OPTIMIZATION OF ROASTING CONDITIONS OF HAZELNUTS IN MICROWAVE ASSISTED OVENS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

NALAN UYSAL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
FOOD ENGINEERING

FEBRUARY 2009

Approval of the thesis:

OPTIMIZATION OF ROASTING CONDITIONS OF HAZELNUTS IN MICROWAVE ASSISTED OVENS

submitted by **NALAN UYSAL** in partial fulfillment of the requirements for the degree of **Master of Science in Food Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Graduate School of **Natural and Applied Sciences**

Prof. Dr. Zümrüt B. Ögel
Head of Department, **Food Engineering**

Prof. Dr. Servet Gülüm Şumnu
Supervisor, **Food Engineering Dept., METU**

Prof. Dr. Serpil Şahin
Co-Supervisor, **Food Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. Ferhunde Us
Food Engineering Dept., Hacettepe University

Prof. Dr. Servet Gülüm Şumnu
Food Engineering Dept., METU

Prof. Dr. Serpil Şahin
Food Engineering Dept., METU

Assoc. Prof. Dr. Esra Yener
Food Engineering Dept., METU

Dr. Behiç Mert
Food Engineering Dept., METU

Date: 03/02/2009

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.

Name, Last name : Nalan UYSAL

Signature :

ABSTRACT

OPTIMIZATION OF ROASTING CONDITIONS OF HAZELNUTS IN MICROWAVE ASSISTED OVENS

Uysal, Nalan
M.S., Department of Food Engineering
Supervisor: Prof. Dr. Gülüm Şumnu
Co-Supervisor: Prof. Dr. Serpil Şahin

February 2009, 105 pages

The main objective of this study was to optimize the roasting conditions of hazelnuts in microwave-infrared and microwave-convective heating combination ovens by using response surface methodology. It was also aimed to construct regression models for the prediction of quality parameters of hazelnuts as a function of processing conditions. The independent variables were microwave power (10, 30, 50, 70 and 90%), upper-lower infrared power (10, 30, 50, 70 and 90%) and roasting time (2, 3, 4, 5 and 6 min) for microwave-infrared combination roasting. Microwave power (70, 140 and 210W), air temperature (90, 150 and 210°C) and roasting time (5, 15 and 25 min) were the independent variables of microwave-convective heating combination oven. As control, hazelnuts roasted in conventional oven at 150°C for 20 min were used. The quality parameters were L* value, a* value, fracture force and moisture content of the hazelnuts for both microwave assisted ovens.

The optimum roasting conditions of microwave-infrared combination oven were determined as 2.5 min of roasting time at 613.8W microwave power, 1800W upper infrared power, and 300W lower infrared power. Hazelnuts roasted at the optimum condition had comparable quality with the conventionally roasted ones. When micro-wave infrared combination oven was used, conventional roasting time of hazelnuts was reduced by 87.5%. Optimum roasting conditions of microwave-convective heating combination oven were 140 W microwave power, 150°C air temperature and 20 min roasting time. High regression coefficients were calculated between the experimental data and predicted values showing that RSM is capable in predicting quality parameters of hazelnuts during microwave assisted roasting.

Keywords: Roasting, Hazelnut, Microwave, Infrared, Response Surface Methodology.

ÖZ

MİKRODALGA- YARDIMLI FIRINLARDA FINDIĞIN KAVRULMA KOŞULLARININ OPTİMİZASYONU

Uysal, Nalan

Yüksek Lisans, Gıda Mühendisliği

Tez Yöneticisi: Prof. Dr. Gülüm Şumnu

Ortak Tez Yöneticisi: Prof. Dr. Serpil Şahin

Şubat 2009, 105 sayfa

Çalışmanın ana amacı, mikrodalga-kızılötesi ve mikrodalga-konvektif ısıtma kombinasyonlu fırınlarda fındıkların kavrulma koşullarının yanıt yüzey metodu ile optimizasyonudur. Fındığın kalite parametrelerini işlem koşullarına göre açıklayan modellerin oluşturulması da amaçlanmıştır. Mikrodalga-kızılötesi fırın için bağımsız değişkenler mikrodalga gücü (10, 30, 50, 70 ve 90%), üst-alt kızılötesi gücü (10, 30, 50, 70 ve 90%), ve kavurma zamanı (2, 3, 4, 5 ve 6 dak) dır. Mikrodalga-konvektif ısıtma kombinastonlu fırın için mikrodalga gücü (70, 140 ve 210W), hava sıcaklığı (90, 150 ve 210°C), ve kavrulma zamanı (5, 15 ve 25 dak) bağımsız değişkenlerdir. Kontrol olarak, 150°C'de 20 dak boyunca konvansiyonel fırında kavrulmuş fındıklar kullanılmıştır. Hem mikrodalga-kızılötesi hem de mikrodalga-konvektif ısıtma kombinasyonlu fırınlarda L* değeri, a* değeri, kırılma kuvveti ve nem miktarı, fındık için belirlenen kalite parametreleridir.

Mikrodalga-kızılötesi fırında optimum kavrulma koşulları 2.5 dak. kavrulma zamanı, 618.3 W mikrodalga gücü, 1800 W üst kızılötesi gücü ve 300 W alt kızılötesi gücü olarak bulunmuştur. Optimum koşullarda kavrulan fındıklar konvansiyonel fırında kavrulanlarla karşılaştırılabilir kalitededirler. Mikrodalga-kızılötesi kombinasyonlu fırın kullanıldığında, konvensiyonel kavurma zamanı %87.5 azalmıştır. Mikrodalga-konvektif kombinasyonlu fırında optimum kavrulma koşulları 140 W mikrodalga gücü, 150°C hava sıcaklığı ve 20 dak kavrulma zamanıdır. Deneysel veriler ve tahmini veriler arasında belirlenen yüksek regresyon katsayıları yanıt yüzey methodun mikrodalga yardımlı fırınlarda kavrulan fındıkların kalite parametrelerinin tahmin edilmesinde başarılı olduğunu göstermektedir.

Anahtar sözcükler: Kavurma, Fındık, Mikrodalga, Kızılötesi, Yanıt Yüzey Metodu.

Dedicated to my family...

ACKNOWLEDGEMENT

I wish to express my sincere gratitude and respect to my supervisor Prof. Dr. Gülüm Şumnu and my co-supervisor Prof. Dr. Serpil Şahin for their continuous support, encouragement, and valuable suggestions in every step of my study.

My thanks are extended to Deniz Çekmecelioğlu and my research group friends Nadide Seyhun, Işıl Barutçu Mazı and Elif Turabi for helping me during my experimental studies and answering patiently to all of my questions. I would also like to thank all of my friends Cem, Hande Baltacıoğlu, Mete Çevik, Sencer Buzrul, Erkan Karacabey, Gökçen Mazı, Neslihan Altay, Işınsu Erdemir, Ertuğrul Doğan and especially Oya Nihan Uncu and Eda Cilvez for helping me to smile everyday.

My very special thanks go to Faruk Yazıcıoğlu for his precious support and love in my life.

I would like to thank Fındık Tanıtım Grubu for sending me hazelnuts.

Finally, I would like to express my deepest gratitude to my mother, father and my little, pilot brother for their endless love and encouragement. I am very grateful to them for their patience and endless support in every step of my education. Words are incapable to express my appreciation to them.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

1.1 Microwave-Infrared Combination Heating of Foods

Microwave-infrared combination heating is a novel technology which combines the time and energy saving advantage of microwave heating with the browning and crisping advantages of infrared heating. It was recommended for baking of bread (Keskin et al., 2004), cake (Sevimli et al., 2005) and rice cake (Turabi et al., 2008). Besides the baking processes, microwave-infrared combination heating was suggested to be used for drying of carrots which can be used in the industry of instant soups and snack foods (Sumnu et al., 2005).

1.1.1 Microwave Heating Mechanism

The usage of microwaves as a heat source began at 1940s for preservation of baked products (Mermelstein, 1997, Lorenz et al., 1973). The primary industries using this technique are the food and chemical engineering industries. Application areas of microwave include polymer and ceramics industries (Ayappa et al., 1991; Chatterjee et al., 1998), medicine (O'Brien and Mekkaoui, 1993; Paulsen et al., 1998) and food processing (Alton, 1998; Fakhouri and Ramaswamy, 1993). Microwave energy can be employed in the area of cooking, thawing, tempering, drying, freeze-drying, pasteurization, sterilization, baking, heating and re-heating in the food industry (Ayappa et al., 1991).

Microwaves are electromagnetic waves of radiant energy having wavelength between radio and infrared waves on the electromagnetic spectrum (Giese, 1992).

Microwaves are usually generated by an electromagnetic device called a "magnetron". Microwaves radiate outward from this source and can be absorbed, transmitted, and reflected (Giese, 1992). Microwaves which are used in the food industry in most of the world for heating are at the frequency of either 2450 MHz or 915 MHz, corresponding to 12 cm or 34 cm in wavelength (Ohlsson and Bengtsson, 2002).

There are two microwave heating mechanisms: ionic conduction and dipolar rotation. In Figure 1.1, the illustration of ionic conduction and dipolar rotation mechanisms of microwave heating are shown. Because of the molecular friction resulting from dipolar rotation of polar solvents and from the conductive migration of dissolved ions, microwave energy penetrates into a food material and produces a volumetrically distributed heat source. The dipolar rotation and ionic conduction are caused by variations of the electrical and magnetic fields in the product (Alton, 1998).

The driving forces of microwave heating mechanism for heat and mass transfer are different from conventional methods. Heat is generated throughout the material in microwave heating whereas in conventional heating heat is usually transferred from the surface to the interior. In foods heated by microwave, time-temperature profiles within the product are caused by internal heat generation owing to the absorption of electrical energy from the microwave field and heat transfer by conduction, convection and evaporation (Mudgett, 1982). Because of the low ambient temperature in the microwave oven and the cooling effects of evaporation, the interior temperature of a food heated by microwave energy is hotter than the surface temperature (Decareau, 1992). A porous media was found to be hotter in the inside when heated by microwaves and hotter on the outside when heated by convection (Wei et al., 1985a, 1985b). Thus, microwave heating leads to faster heating rates and shorter processing times compared to conventional heating. Besides faster heating, other advantages of microwave heating include space savings, energy efficiency, precise process control, selective heating and production food with high nutritional quality (Decareau and Peterson, 1986).

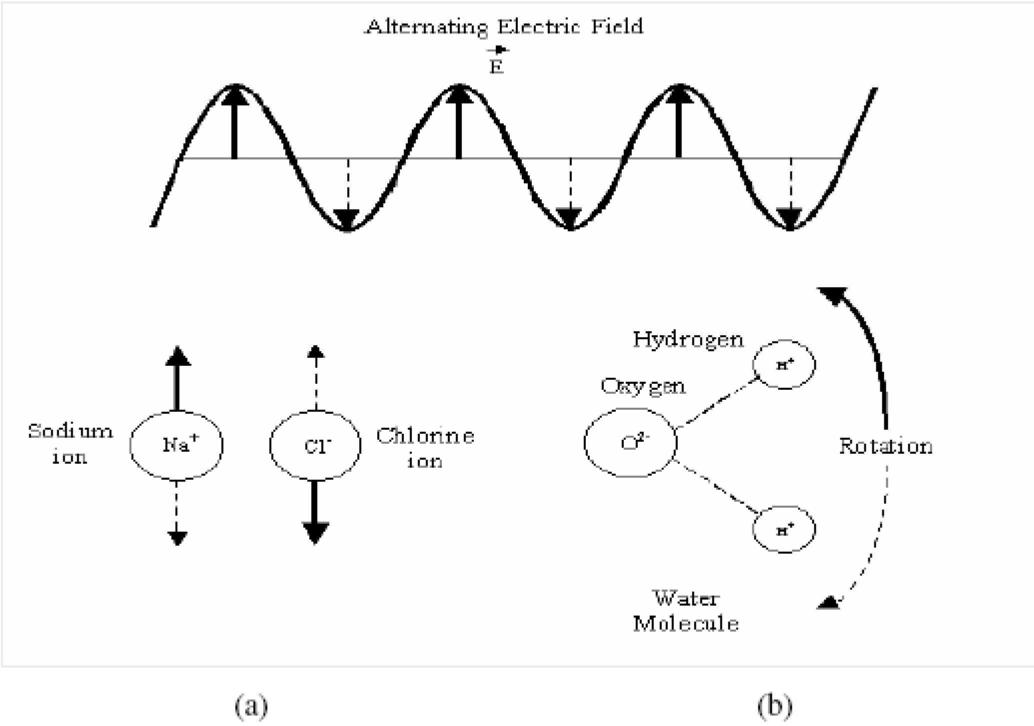


Figure 1.1 Microwave heating mechanisms (a) Ionic conduction (b) Dipolar rotation (Sahin and Sumnu, 2006)

For microwave heating, the energy equation includes a heat generation term;

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + \frac{Q}{\rho C_P} \tag{1.1}$$

where T is temperature (K), t is time (s), α is thermal diffusivity (m^2/s), ρ is density (kg/m^3), Cp is specific heat of the material (J/kg.K) and Q is the rate of heat generated per unit volume of material ($J/s.m^3$).

The heat generated per unit volume of material per unit time (Q) represents the conversion of electromagnetic energy. Its relationship to the electric field intensity (E) at that location can be derived from Maxwell's equation of electromagnetic waves as shown by Metaxas and Meredith (1983);

$$Q = 2\pi\varepsilon_0\varepsilon'' f E^2 \tag{1.2}$$

where ε_0 is the dielectric constant of free space, ε' is the dielectric loss factor of the food, f is the frequency of oven and E is the electric field intensity. In equation (1.2), magnetic loses of the food material have been ignored.

The dipolar nature of water, the major constituent of most food products, makes water as the main source for microwave interactions. Compared to conventional heating, moisture flows, owing to concentration and pressure gradients, are uniquely and significantly altered during microwave heating. Relatively large amounts of internal heating seem to result in increased moisture vapor generation inside a solid food material, which creates significant internal pressure and concentration gradients (Datta, 1990). This positive pressure increase causes the flow of vapour and liquid through food to the boundary. Governing equation for mass transport in microwave processing is;

$$\frac{\partial M}{\partial t} = \alpha_m \nabla^2 M + \alpha_m \delta_P \nabla^2 P \tag{1.3}$$

where M is the total moisture content (liquid and vapour phases), α_m is the moisture diffusivity, δ_p is the pressure gradient coefficient and P is pressure.

1.1.2 Infrared Heating Mechanisms

Infrared (IR) radiation is the part of the sun's electromagnetic spectrum that is predominantly responsible for the heating effect of the sun (Ranjan et al., 2002). Infrared radiation is found between the visible light and radiowaves (Sepulveda and Barbosa-Canovas, 2003) and can be divided into three different categories; near-infrared radiation (NIR), mid-infrared radiation (MIR) and far infrared (FIR) radiation (Ranjan et al., 2002).

Infrared heating provides near-infrared radiation. Its region in the electromagnetic spectrum is near the visible light with higher frequency and lower penetration depth than the other infrared radiation categories. Infrared heating is transferred by radiation which cannot be ignored and often it has a high temperature (500-3000°C). The penetration depth of infrared radiation has a significant influence on how much the surface temperature increases or the level of surface moisture after the process. Penetration depths of infrared radiation can vary significantly for various food materials. Datta and Ni (2002) showed that as the infrared radiation penetration depth decreases, the surface temperature increases. Infrared heating provides an imperative place in drying technology and extensive research work has been conducted in this area. Application of infrared drying in the food industry is expected to represent a new process for the production of high-quality dried foods at low cost (Sakai and Hanzawa 1994). The use of IR radiation technology for dehydrating foods has numerous advantages including reduced in drying time, alternate energy source, increased energy efficiency, uniform temperature in the product during drying, better-quality finished products, reduced necessity for air flow across the product, high degree of process control parameters, space saving along with clean working environment, decreased chance of flavor loss, preservation of vitamins in food products, and absence of solute migration from inner to outer regions (Dostie et al., 1989; Ranjan et al., 2002; Navari et al., 1992; Sakai and Hanzawa 1994; Mongpreneet et al., 2002). For drying of fruit and vegetables, IR drying was applied on products such as potatoes (Masamura et al., 1988; Afzal and Abe, 1998), sweet potatoes (Sawai et al., 2004), onions (Mongpreneet et al., 2002; Sharma et al., 2005), kiwifruit (Fenton and Kennedy 1998), and apples (Nowak and Levicki, 2004; Togrul 2005). The advantages of IR heating has also been used in various other food processing applications such as roasting, frying, broiling, heating, and cooking meat and meat products, soy beans, cereal grains, cocoa beans, and nuts (Sakai and Hanzawa, 1994; Dagerskog, 1979; Khan and Vandermey, 1985; AbdulKadir et al., 1990; Sheridan and Shilton, 1999; Fasina et al., 1996; Lee et al., 2006).

1.2 Hazelnut

The Common Hazel (*Corylus avellana*) is a species of hazel native to Europe and western Asia, from the British Isles south to Turkey, Iberia, Greece, and Cyprus, north to central Scandinavia, and east to the central Ural Mountains, the Caucasus, and northwestern Iran. Turkey is the most important producer of hazelnut among the hazelnut producers in the world with an average annual production of 510000 tons; it is followed by Italy (100000 tons/year), USA (28000 tons/year) and Spain (20000 tons/year). Besides the production, it has the largest export capacity with a 1.5 billion US$ revenue, annually (World Hazelnut Production Statistics, Fiskobirlik Company). For the last 6 centuries, hazelnut has been exported from Turkey to other countries. (Hazelnut Promotion Group). For the cultivation of hazelnut, regions with mild, moist winters and cool summers were preferred. Hazelnut trees blossom and effloresce in mid-winter, grow for the next few months and harvested by late October. Turkish hazelnuts are classified as "round" with a width to length ratio 1.00±0.19 and "point" with a ratio of 1.3±0.10 in general (Özdemir, 2001). Round hazelnuts are in mid size and known to have better quality than point ones in terms of taste and texture. Hazelnut which has a unique and unrivalled flavor is used as an ingredient in variety of food products both in raw and roasted form. 80% of hazelnut is consumed as an ingredient in chocolate manufacture, 15% in confectionary, biscuit and pastry manufacture, and the rest are consumed without any processing (Altundağ, 1989; Anonymous, 1995; Köksal and Okay, 1996). Hazelnut can be used as a flavoring agent in food products such as dairy, bakery, confectionary products and muesli. It also enhances the flavor and the texture to an increasing variety of sweet and savoury food products such as chocolate, ice cream, cookies, and desserts (Ozdemir, 2001). Due to the positive changes of its organoleptic properties, hazelnut is generally preferred in roasted form in sweets, confectionary, chocolate and biscuits (Demir and Cronin, 2005).

Since hazelnuts have rich and qualified compositions of protein, fat, vitamin and mineral, they become among the essential food products for healthy human nutrition. Alasalvar et al. (2003) determined the compositional characteristics of Tombul (round) hazelnuts. The proximate composition, caloric value, mineral and vitamin content, amino acid, free fatty acid compositions of Tombul hazelnut were given in Appendix A (Alasalvar et al, 2003). Fat was found to be the predominant component in hazelnut ranging from 59.3 to 69.0% (Amaral et al., 2006). It has lower saturated fatty acids (10%) than olive oil (15%) and higher unsaturated fatty acids (oleic acid). Amaral et al. (2006) confirmed that hazelnut was a rich source of oleic acid (about 80%), which has been associated with beneficial health effects. As compared to olive oil, hazelnut oil has the advantage of presenting lower contents of saturated fatty acids. Hazelnuts also contain several phytosterols generally in higher amounts than most of the olive oil samples, which appear to be important bioactive compounds since they can inhibit intestinal absorption of cholesterol. Richardson (1996) also emphasized that nuts possess substances which significantly reduce risk of coronary heart disease, some types of cancer, and several other diseases and physiological conditions and syndromes. Hazelnut proteins are relatively rich in amino acids such as lysine (Keskin, 1981). Hazelnut also contains calcium, zinc and iron which are the essential minerals for growth. Potassium which is required for muscle and nerve system is also available in high levels in hazelnuts. Hazelnut is also a good source of phosphorus which is necessary for healthy bones and tooth (Alphan et al., 1996; Açkurt et al., 1999; Şimşek and Aslantaş, 1999). Apart from the magnesium and potassium, selenium was among the major minerals present in hazelnut. Among the tree nuts, hazelnut was reported to be the best source of vitamin E (Holland et al., 1995) and a good source of natural antioxidants (Yurttaş et al., 2000) and dietary fiber (Alasalvar et al, 2003). Richardson (1996) stated that only 25 g of daily hazelnut intake compensates for 100% of vitamin E and 25% of vitamin B_6 of daily requirement. Thompson (1994) revealed that vitamin E and α-tocopherol, which are lipid soluble phenolic antioxidants, are able to scavenge free radicals and are believed to have an active role in the prevention of cancer, atherosclerosis, and diabetes. Dietary fiber content, which is an indicator of a good nutritional value, is used in the preparation of fiber-based foods and dietary supplements. It is known to have therapeutic implications for diabetes, hyperlipidemia, and obesity and may show a protective effect against hypertension, coronary heart disease, cholesterol, colorectal and prostate cancers, and intestinal disorders obesity (Anderson et al., 1988; Kritchevsky, 1988; Johnson et al., 1994; Brown et al., 1999; Tariq et al., 2000).

1.3 Roasting

Roasting is a time-temperature dependent process which causes several changes such as heat exchange, chemical reactions and drying. These changes lead to an improvement in flavor, color, texture, and appearance. In addition, free amino acids, peptides (Montavon et al., 2003), fatty acids, vitamin E, phytosterols and lignans (Murkovic et al., 2004) are found to be changed during roasting process. By roasting, enzymes that cause nutrient loss can be inactivated and undesirable microorganisms, toxins or allergens and food contaminants can be destroyed, and the pellicles of hazelnut kernels can be removed (Ozdemir and Devres, 2000a,b).

1.3.1 Effects of Roasting on Quality of Foods

Since the enzymes responsible for browning are denatured due to the high temperatures employed during industrial roasting of nuts (>100°C), the possibility of enzymatic browning was considered to be negligible (Troller, 1989; Driscoll and Madamba, 1994). Therefore, the chemical reaction responsible for the enhancement of color, texture, flavor and appearance is mainly non-enzymatic browning. Non-enzymatic browning is not a single reaction, but a complex set of reactions. These reactions can be divided into three primary flavor generating reactions: sugar caramelization, Maillard reaction, and oxidation of ascorbic acid. Maillard reaction involves the reaction between the carbonyl group of a reducing sugar with a free, uncharged amine group of an amino acid or protein with the loss of one mole of water. (Buckholz et al., 1980; Mayer, 1985; Perren and Escher, 1996; Lopez et al., 1997). Thus, non-enzymatic browning may cause decrease in the nutritive properties of the food since there exist certain decrease in protein digestibility and solubility of the product, loss of essential amino acids and vitamins, development of off-flavor, undesirable color and textural changes, and increase in acidity (Ames, 1988; Troller, 1989; Villota and Hawkes, 1992; Labuza and Braisier, 1992; Jinap et al., 1998). Non-enzymatic browning products have also anti-oxidant properties. Antioxidant properties are related to the formation of phenolic type structures and/or the metal chelating properties of melanoidins (Ames, 1988; O'Brien and Morrissey, 1989; Nicoli et al., 1991; Perren and Escher, 1996a,b).

The rate of non-enzymatic browning is strongly dependent on material composition, temperature, moisture content, and pH (Labuza, 1980; Labuza and Baisier, 1992). Since reactant mobility increases as moisture content of the food increases, the rate of non-enzymatic browning increases. The maximum browning rate occurs when food has intermediate water activity levels of 0.40-0.60. The non-enzymatic browning rate decreases after the browning-critical moisture content has been reached (Karel, 1984; Troller, 1989).

Since roasting is a time-temperature dependent process, another similar process which is drying also occurs during roasting. Drying is considered to be mainly responsible for textural changes (Mayer, 1985; Perren and Escher, 1996a,b; Saklar, 1999; Saklar et al., 2001). Although hazelnut has low initial moisture content (5-9%), moisture loss occurs during roasting due to the high temperature applied (>100ºC). Saklar (1999) pointed out that moisture loss can be influenced by roasting temperature, roasting time, air velocity, product characteristics, and roaster characteristics, all of which are related to heating performance.

Ozdemir et al. (2000) analyzed the color change of hazelnut during conventional roasting. They suggested that establishment of objective quality control system was necessary for hazelnut roasting. They emphasized the importance of roasting conditions (roasting time and temperature) on affecting the main quality attributes of roasted hazelnuts which are moisture (related to texture), color and rancidity. They found that roasting temperature is the main factor affecting color development during roasting of hazelnuts.

The first quality impression made by a consumer is the appearance of a food. Color, taste, odor, and texture analyses of foods are used in order to monitor of food quality throughout and at the end of processing (Hunter, 1976). Color is, perhaps, the most important attribute because abnormal colors, especially those associated with deterioration in eating quality or with spoilage, cause the product to be rejected by the consumer (Clydesdale, 1976). The improvement in hazelnut color during roasting has a direct connection with non-enzymatic browning, since the brown pigments increase as non-enzymatic browning and also caramelization reactions progress (Moss and Otten, 1989). It has been verified by Özdemir (2001) that sugar caramelization, the thermal dehydration and fragmentation of sugars also yield brown pigments besides organic acids and various aldehydes and ketones. Caramelization reaction also causes unwanted burnt flavors. The color measurement can be used in an indirect way to estimate coloured compounds of food, since it is simpler and faster than chemical analysis (Clysdedale, 1976; Hunter, 1976; Francis, 1983).

The main reason of applying heat treatments on certain foods is to promote flavor changes that fundamentally increase overall palatability of the product. In this manner, peanuts, almonds, hazelnuts and other nuts, coffee, cocoa and other similar products are subjected to heat treatments such as roasting. After certain heating, the volatile components are released giving rise to flavor enhancement. Free amino acids and monosaccharides are essential flavor precursors for the development of unique flavors during roasting (Newell et al., 1967; Mason et al., 1969). Free amino acids and monosaccharides which are the building blocks of polypeptides and complex carbohydrates in peanuts, are released from these respective macromolecules through undefined processes resulting from hydrolysis under specific conditions during roasting. It has been found that free amino acid contents in peanuts after 10 min of roasting were higher than those in unroasted peanuts and the changes in specific amino acid content were found to be dependent upon time of roasting and initial moisture content (Chiou et al., 1991). Among the amino acids, aspartic acid, glutamic acid, glutamine, histidine, asparagine, and phenylalanine are precursors of flavor together with threonine, tyrosine, and lysine (Newell et al., 1967). It was stated previously that sucrose participated in flavor development through its inversion to glucose and fructose during the browning process (Mason et al., 1969; Reyes et al., 1982). It was also noted that chemical composition (precursor levels) of peanuts was affected by several factors such as variety, location, climatic conditions, maturity, curing (Oupadissakoon et al., 1980; Mason et al., 1969), seed size, and storage (Pattee et al., 1982)

Schenker et al. (2002) studied the effect of roasting conditions on the formation of aroma compounds in coffee beans. They confirmed that roasting was the main flavor determinant process. The greatest aroma formation rates during roasting were found at the medium stages of product dehydration. At least one roasting phase at a medium temperature level was found to be essential in generating sufficient aroma intensity, while high-temperature conditions could alter the aroma profile and should be avoided.

Alasalvar et al. (2003) observed the differences between raw and roasted hazelnuts in terms of flavor. Seventy-nine compounds including ketones, aldehydes, pyrazines, alcohols, aromatic hydrocarbons, furans, pyrroles, terpenes, and acids were determined for raw and roasted hazelnuts. Pyrazines, pyrroles, terpenes, and acids were found to be present only in roasted hazelnut. They observed that concentrations of several compounds, playing significant roles in the flavor of roasted hazelnut, increased as a result of roasting. Pyrazines together with ketones, aldehydes, furans, and pyrroles were the compounds which may contribute to the characteristic roasted aroma of hazelnut. Baker et al. (2003) also performed a study on pyrazine in order to monitor the flavor changes during roasting of coffee beans.

Roasting gives hazelnuts a variety of texture increasing the crispness and crunchiness (Saklar et al., 1999; Ozdemir and Devres, 1999; Ozdemir et al., 2001). There are several factors which influence the variability in the texture of nuts. According to Demir and Cronin (2004), the variation in physical properties, such as size, shape and mass, due to hazelnuts biological origin may affect the texture of hazelnut. Ripeness is one of the factors, which affects the variability in physical properties of hazelnuts. Since hazelnuts have different sizes and shapes, the temperature profile of each nut will vary, resulting in different quality during thermal processing. Another factor increasing the variability is the variation in the thermal properties of hazelnuts, such as thermal conductivity, specific heat capacity and density. Furthermore, in agricultural materials, temperature and moisture content greatly influence the thermal properties.

Thermal properties are known to change with composition however the composition of hazelnut show differences between varieties as well as within the same variety. Force deformation curves are widely used to monitor these textural changes in hazelnuts. Initial slope, maximum force, energy, fracture points or other curve-related parameters have been analysed and correlated with these textural parameters (Demir and Cronin, 2004). Saklar et al. (1999) determined the instrumental texture measurements of roasted hazelnuts with compression tests. The results were found to be correlated with sensory crispness and crunchiness.

During roasting, foods can undergo rancidity reactions which cause spoilage, because of the odd colors and flavors formed. The major oxidative reactions in foods are due to peroxidation of lipids. Lipid oxidation in foods is associated almost exclusively with unsaturated fatty acids and it is often autocatalytic, with oxidation products themselves catalyzing the reaction so that the rate increases with time (Karel, 1985). Lipid hydrolysis is an enzymatic reaction catalyzed by lipase. The hydrolysis of the lipids results in a progressive increase of the food acidity, caused by the formation of free fatty acids. Therefore, lipid hydrolysis favours the lipid oxidation because the fatty acids formed can be substrates of the oxidation reaction (Richardson, 1984; Gomez and De la Torre. 1989). Since hazelnut is a nut with a high lipid content (about 60% of kernel weight), and very rich in unsaturated fatty acids (Parcerisa et al., 1993), it is a very sensitive product owing to rancidity.

1.3.2 Microwave Roasting

The application of microwave heating to culinary techniques and food processing is a recent addition to traditional cooking techniques such as roasting, boiling, and frying (Anjum et al., 2006). Knowing the distinct advantages of microwave heating such as high speed of operation, energy saving, precise process control, faster start up and shut-down times, several researchers applied microwave roasting in various foods and oil extracted from these foods such as cumin seed (Behera et al., 2004), peanut (Megahad, 2001; Yoshida et al., 2003), sunflower seed (Yoshida et al., 2002; Anjum et al., 2006), pumpkin seed (Yoshida et al., 2006), sesame seed (Yoshida et al., 1995) and coffee beans (Nebesny and Budryn, 2003).

In the study of microwave heating and the conventional roasting of cumin seeds, it was found that the microwave-heated samples showed better retention of characteristic flavor compounds, such as aldehydes, compared to the conventionally roasted sample (Behera et al., 2004). In another study on pumpkin seeds, it was concluded that microwave roasting did not have any adverse effects on seed or oil quality, and the use of short-term microwave roasting to reduce seed moisture and to retard seed deterioration was recommended (Yoshida et al., 2003). During the process of coffee bean roasting, results showed that less hydroxymethylfurfural (HMF) was formed upon microwave heating than upon convective heating (Nebesny, and Budryn, 2003). Nebesny, and Budryn (2006) also stated that microwaving of more humid coffee beans caused the lowest decline in lipid content and the weakest changes in oil quality. There are some reports suggesting that retention of nutrients such as vitamins in microwaved foods was improved when the roasting time was shortened. Yoshida and Tagaki (1996) suggested that microwave roasting of raw beans might be an effective means for producing full-fat soya flour with high vitamin E. However, other studies indicated that nutrient retention during microwave processing was not much greater than that in conventional cooking (Tagaki et al., 1999). Barac and Stanojevic (2005) studied the effect of microwave roasting on protease inhibitor activity and soluble protein content and composition in cracked soybeans in relation to the duration of treatment. The study was concluded with the results revealing that microwave treatment was an effective way for inactivation of protease inhibitor activity in cracked soybeans. Roasting for only two minutes reduced the trypsin inhibitor activity.

There is a study on microwave roasting of hazelnut which actually aims to elucidate the lipid classes, the fatty acid profiles, the triacylglycerol, and sterol compositions of raw and microwaved roasted walnuts, hazelnuts and almond kernels. No changes in lipids of microwave roasted nuts were detected and ready-to-consume nuts were obtained by this process (Momchilova and Damyanova, 2007). There is no study in literature on roasting of foods by microwave-infrared and microwave-convective heating combinations. In this study, the advantages of microwave heating was combined with infrared heating and convective heating for roasting of hazelnuts.

1.3.3 Infrared Roasting

There are studies in which infrared radiation was applied. Mahajan and Pai (1988) roasted whole peanuts by infrared lamp at temperatures between 150°C and 230°C for 1 to 15 min and compared the quality results with conventional roasting. They concluded that peanuts roasted by infrared took less roasting time and lost more oil even though the moisture content was fairly high after roasting. Sakai and Hanzawa (1994) reported on the performance of infrared systems with conventional ovens for roasting fish and found that more than 25% energy was saved with infrared heating.

1.4 Response Surface Methodology

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes (Myers and Montgomery, 2002). It uses quantitative data to determine and simultaneously solve multivariate equations, which specify the optimum product for a specified set of factors through mathematical models. These models consider interactions among the test factors and can be used to determine how the product changes with variations in the factor levels. RSM is more efficient than traditional experimental procedures because it decreases the time and cost required to determine the optimum product (Giovanni, 1983).

The most extensive applications of RSM are in the industrial world, particularly in situations where several input variables potentially influence some performance measure or quality characteristic which is called the response. It is typically measured on a continuous scale, although attribute responses, ranks, and sensory responses are not unusual. Most real-world applications of RSM will involve more than one response. The input variables are sometimes called independent variables, and they are subject to the control of the engineer or scientist, at least for purposes of a test or an experiment (Myers and Montgomery, 2002).

Basically RSM is a four-step process. First, the critical factors that are important to the product or process under study are identified. Second, the range of factor levels which will encompass the physical specifications of the samples are defined. Third, the specific test samples are determined by the experimental design and then tested. Fourth, the data from these experiments are analyzed by RSM and then interpreted.

There are five assumptions in order to use RSM effectively:

1. The factors, which are critical to the product, are known.
2. The region of interest where the factor levels influence the product is known.
3. The factors vary continuously throughout the experimental range tested.
4. There exists a mathematical function that relates the factors to the measured response.
5. The response, which is defined by this function, is a smooth surface.

In addition to these assumptions, the experimenter should be aware of five limitations when using RSM:

1. Large variation in the factors can result in misleading conclusions.
2. The critical factors of the product may not be correctly specified or sufficiently defined resulting in an inaccurate description of the optimum product.
3. The optimum product may not be determined by RSM because the range of factor levels tested was too narrow or too broad to specify the optimum.
4. As with any experiment, biased results can occur if good statistical principles are not followed.
5. Over-reliance on the computer to conduct the experiment can lead to incomplete results. The experimenter must use good judgment and knowledge about the product to draw appropriate conclusions from the data.

In RSM, generally two types of designs are common: Central Composite Design and Box-Behnken Design.

Central composite designs are often recommended when the design plan calls for sequential experimentation because these designs can incorporate information from a properly planned factorial experiment. The factorial or “cube” portion and center points may serve as a preliminary stage where a first-order (linear) model can be fitted, but still provide evidence regarding the importance of a second-order contribution or curvature. Central composite designs usually have axial points outside the “cube”. These points may not be in the region of interest, or may be impossible to run because they are beyond safe operating limits. Central composite designs also allow for efficient estimation of the quadratic terms in the second-order model, and it is easy to obtain the desirable design properties of orthogonal blocking and rotatability. Orthogonally blocked designs allow for model terms and block effects to be estimated independently and minimize the variation in the regression coefficients. Rotatable designs provide the desirable property of constant prediction variance at all points that are equidistant from the design center, thus improving the quality of the prediction (Shuaeib et at., 2007).

Box–Behnken designs are generally recommended when performing non-sequential experiments, that is, when planning to perform the experiment once. These designs allow for efficient estimation of the first and second order coefficients. Because Box–Behnken designs have fewer design points, they are less expensive to run than central composite designs with the same number of factors. Also, Box–Behnken designs can be useful if the safe operating zone for the design under consideration is known. Box–Behnken designs do not have axial points, thus, all design points will fall within the safe operating zone. In addition, Box–Behnken designs ensure that all factors are never set at their high levels simultaneously (Shuaeib et al., 2007).

In this study, multiple response optimization was performed by using the response optimizer option of MINITAB. After MINITAB calculates an individual desirability, which is a measure of how well the combined goal for the response have been satisfied, for each response, they are combined to provide a measure of the composite, or overall, desirability of the multi-response system. The individual desirabilities are weighted according to the importance that is assigned to each response. This measure of composite desirability is the weighted geometric mean of the individual desirabilities for the responses. The optimal solution (optimal operating conditions) can then be determined by maximizing the composite desirability.

There are some studies in the literature in which RSM was used to optimize roasting process (Saklar et al., 2001; Kahyaoglu and Kaya, 2006). However; there is no information in the literature about the optimization of microwave-infrared and microwave-convective heating combinations for roasting of hazelnuts using RSM. Thus, in this study, it was aimed to optimize the conditions of roasting of hazelnut in microwave-infrared and microwave-convective heating combination ovens by using RSM.

1.5 Objectives of the Study

The largest parts of processed hazelnuts are the whole roasted kernels and their products. They are used as ingredient in chocolate, ice-cream, confectionary, and cookie industry in order to provide nutritional benefits, and to improve color, flavor, crispy and crunchy texture of foods. In Turkey, nearly four million people are directly or indirectly related to hazelnut production which has been produced on an area of 550-600 thousand hectares. Highly qualified Turkish hazelnuts have unique place among the other hazelnuts in the world. They maintain this leading position in production and also in exportation.

Microwave-infrared combination heating has the advantage of reduction of conventional processing time. This method can be an alternative to conventional roasting. There is lack of study in literature about microwave-infrared and microwave-convective heating combinations for roasting of nuts. Therefore, the main objective of this study was to optimize the roasting conditions in microwave-infrared combination oven and microwave-convective heating combination oven so that the quality of hazelnuts would be comparable with conventionally roasted ones. The quality parameters investigated were color, texture and moisture content of hazelnuts. As an optimization method, Response Surface Methodology (RSM) was used. RSM has many advantages as compared to the other optimization methods since it is a fast, cheap and reliable method.

As specific objectives of the study, the effects of microwave-infrared oven parameters such as upper and lower infrared power, microwave power, and roasting time; and microwave-convective heating combination oven parameters such as air temperature, microwave power and roasting time on the quality of roasted hazelnuts were investigated. It was also aimed to reduce the conventional roasting times by using microwave assisted ovens.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Raw and unshelled hazelnuts having a moisture content of 4.8 ± 0.5%, *a** value of 10.5 ± 0.50, *L** value of 61 ± 0.5 with fracturability of 80 ± 2 N were used in the study. They belong to variety “Tombul”. They were provided from Giresun region (Turkey) by the help of the Hazelnut Promotion Group (http://www.ftg.org.tr /eng_main.htm). Hazelnuts were in round shape. Hazelnuts having a height and diameter of 10 ± 1 mm were chosen for the experiments. Before the experiments, raw hazelnuts were stored in cold room at 4 °C in vacuum packages.

2.2 Methods

2.2.1 Determination of Power of Microwave Oven

IMPI 2-liter test was used for determination of power of microwave oven. The oven was operated on the highest power with a load of 2000±5g of water placed in two 1L Pyrex beakers. Initial water temperature should be 20±2 °C. The beakers were placed in the center of the oven side by side in the width dimensions of the cavity. The oven was turned on for 2 min and 2 s. Final temperatures were measured immediately after the oven was turned off. The power measurement was replicated three times. The power was calculated by using Equation (2.1);

$$P(W) = \frac{70(\Delta T_1 + \Delta T_2)}{2} \tag{2.1}$$

where ΔT_1 and ΔT_2 are the temperature rises of the water in the two beakers calculated by subtracting the initial water temperature from the final temperature (Buffler, 1993). Accordingly, the power of the microwave-infrared combination was determined as 682W. The maximum power of microwave-convective heating combination oven was determined as 210W.

2.2.2 Experimental Design

2.2.2.1 Experimental Design for Microwave-Infrared Combination Roasting

RSM is generally used in situations where several input variables, called "independent variables", potentially influence some performance measure or quality characteristic of the product or process. This performance measure or quality characteristic is called the "response". The independent variables in the optimization of microwave-infrared roasting study were microwave power (X_1), upper infrared power (X_2), lower infrared power (X_3), and time of the roasting process (X_4).

For convenience of notation, actual X_i variables were coded by using the general transformation;

$$x_{ui} = \frac{X_{ui} - a_i}{c_i} \tag{2.2}$$

where x_{ui} is coded factor level, X_{ui} is factor level, a_i is mid value of the factor levels and c_i is the range between the two values of levels of each factor.

The use of coded levels has several advantages. By using coded variables, experimental designs can be written without the need of showing the interest range for each input variable. Also, regression coefficients can be compared easily and directly since each of the variable's range is the same.

The actual values and the corresponding coded values of independent variables which cover a broad spectrum of available operating conditions are given in Table 2.1.

Table 2.1 The coded and actual values of the levels of the independent factors

Operating Conditions		Coded Levels				
		-2	-1	0	1	2
		Uncoded Levels				
Microwave Power	(%)	10	30	50	70	90
	(Watt)	68.2	204.6	341.0	477.4	613.8
Upper Infrared Power	(%)	10	30	50	70	90
	(Watt)	300	900	1500	2100	2700
Lower Infrared Power	(%)	10	30	50	70	90
	(Watt)	150	450	750	1050	1350
Roasting Time	(min)	2	3	4	5	6

Due to four factors and their five levels for microwave-infrared roasting, Central Composite Design (CCD) was adopted. CCD is an experimental design, useful in response surface methodology, for building a second order (quadratic) model for the response variables. CCD consists of a complete (or fraction of) 2^k factorial design, n_0 center points, and two axial points on the axis of each design variable at a distance α from the design center (McKellar and Lu, 2004). These models consider interactions among the test factors and can be used to determine how the product changes with changes in the factor levels (Giovanni, 1983). CCD is generally used in many food processes (Ozdemir and Devres, 2000a; Saklar et al., 2001; Demirekler et al., 2004). The effects of independent variables were analyzed on responses which are L* value representing lightness, a* value greenness and redness of color dimensions, fracture force, and moisture content. Experimental design is shown in Table 2.2. Central composite design having 30 experimental runs with different combination of factors was conducted using MINITAB® Release 14.1 (Minitab Inc. State College, PA, USA) in order to study the main effects and interactions. In order to provide uniform variance at any given radius from the center of the design mainly, rotatability and orthogonality, the axial distance, α, was chosen to be 2. The number of cube points, axial points, and center points in the design are 16, 8 and 6, respectively. To make each run in the design independent of each other, MINITAB® Release 14.1 (Minitab Inc. State College, PA, USA) tool of randomization was used. The assigned run order was taken into account during the experiments.

Table 2.2 Experimental points of the Central Composite Design

Experiment number	Microwave Power	Upper Infrared Power	Lower Infrared Power	Roasting Time
1	1	-1	-1	-1
2	-1	1	-1	-1
3	-1	-1	1	-1
4	1	1	1	-1
5	-1	-1	-1	1
6	1	1	-1	1
7	1	-1	1	1
8	-1	1	1	1
9	-1	-1	-1	-1
10	1	1	-1	-1
11	1	-1	1	-1
12	-1	1	1	-1
13	1	-1	-1	1
14	-1	1	-1	1
15	-1	-1	1	1
16	1	1	1	1
17	-2	0	0	0
18	2	0	0	0
19	0	-2	0	0
20	0	2	0	0
21	0	0	-2	0
22	0	0	2	0
23	0	0	0	-2
24	0	0	0	2
25-30	0	0	0	0

2.2.2.2 Experimental Design for Microwave-Convective Heating Combination Roasting

In this study, RSM was conducted by Box-Behnken Design which is one of the most common experimental designs used for engineering purposes. Through Box-Behnken Design, the effect of microwave power (X_1), air temperature (X_2), and time of the roasting (X_3) on L* value and a* value of color, texture and moisture content of hazelnut were investigated. Each independent variable was included in the design at three levels rather than five levels required for a central composite design or the four levels for a San Cristobal design (Thomson, 1982). Only integers (-1, 0, +1) for coded levels were used for Box Behnken design. This design for three variables consisted of a combination of the following subsets of points from full factorial, 3^3 design. There were points at (±1, 0, 0; 0, ±1, 0; 0, 0, ±1) and center points (Khuri and Cornell, 1987). Center points were the replicated points at the center of the design. These points had all coordinates (0,……,0). These points provided a mean for estimating the experimental error and provide a measure of lack of fit with one degree of freedom.

The actual values and the corresponding coded values of independent variables which cover a broad spectrum of available operating conditions are given in Table 2.3. Experimental design is shown in Table 2.4. Box-Behnken Design having 15 experimental runs with different combination of factors was conducted using MINITAB® Release 14.1 (Minitab Inc. State College, PA, USA).

Table 2.3 The coded and actual values of the levels of the independent factors

Operating Conditions		Coded Levels		
		-1	0	1
		Uncoded Levels		
Microwave Power	(Watt)	70	140	210
Air Temperature	(ºC)	90	150	210
Roasting Time	(min)	5	15	25

Table 2.4 Experimental points of the Box-Behnken Design

Experiment Number	Microwave Power	Air Temperature	Roasting Time
1	1	-1	0
2	1	1	0
3	0	0	0
4	0	-1	-1
5	-1	-1	0
6	-1	0	1
7	0	0	0
8	-1	0	-1
9	1	0	-1
10	1	0	1
11	0	1	1
12	-1	1	0
13	0	1	-1
14	0	0	0
15	0	-1	1

2.2.3. Roasting

In this study, conventional, microwave-infrared, and microwave-convective heating combination ovens were used.

2.2.3.1 Conventional Roasting

In order to determine the constraints for the optimization of microwave–infrared and microwave-convective heating combinations for roasting, hazelnuts were roasted in a commercial electrical oven (Arçelik ARMF 4 Plus, Istanbul, Turkey) at 150 °C for 20 min. About 20 ± 0.5 g of hazelnut samples were supported on a plate for roasting.

2.2.3.2 Microwave-Infrared Combination Roasting

Microwave–infrared combination oven (Advantium Oven™, General Electric Company, Louisville, KY, USA) is shown in Fig. 2.1. It provides both microwave heating and near infrared heating. The cavity size of Advantium oven was 21 cm in height, 48 cm in length, and 33 cm in width. There are three halogen lamps each having a maximum power of 1500 W. Two halogen lamps were located 15 cm above the food surface while the lower lamp was just under the rotary table. The maximum power of microwave determined by IMPI-2L test was 682 W. About 20 ± 0.5 g of hazelnut samples on a plate were roasted at each of the experimental condition.

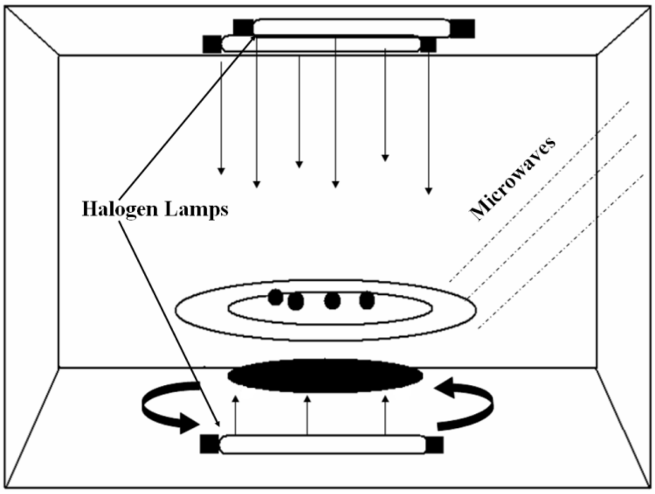


Figure 2.1 Schematic diagram of microwave–infrared combination oven.

2.2.3.3 Microwave-Convective Heating Combination Roasting

For the microwave-convective heating combination roasting, Miele H4050BM oven (Miele Co. LTD, Oxon, UK) was used. It includes a heating system which works by the circulation of hot air. There exists a fan in the back wall of the oven which draws the air, heats it over a ring element and blows it back into the oven cavity through the carefully spaced openings in the back panel. The fan helps the circulation of heat throughout the oven. The maximum available microwave power was 210W which was determined by IMPI-2 liter test.

2.2.4. Color measurement

Color of hazelnut samples was determined by using Minolta Color Reader (CR-10, Japan). Two color values of CIE measurement system were used: L*, a*, and b* values which give the specific color of the material, separately. The L* value represents ‘lightness’, from zero (black) to 100 (white). The a* value represents, ‘greenness’ or ’redness’ ranging from -60 to +60. The b* value represents ‘yellowness’ or ‘blueness’ ranging from +60 to –60. In order to obtain the homogeneity among the runs, 20 randomly selected hazelnuts roasted in corresponding roasting conditions were milled. Six different measurements were performed for each experimental run. The hazelnuts were placed on white paper and no sunlight was allowed to pass into laboratory to provide the same environmental conditions.

2.2.5. Texture measurement

Texture analyzer (Lloyd Ins. TA Plus, Hants, UK) was used for determination of the fracture force. The hazelnut samples with a height of 10 ± 1 mm were compressed by cylindrical probe with 12 mm diameter at a constant deformation speed of 10 mm/min. A load cell of 1000 N was fixed on the moving head of the instrument. The safety limit for the texture analyzer was changed to 150 N to avoid any interruptions. Whole hazelnut samples were placed on the table just under the cylindrical probe. Hazelnut samples, which were not able to stand in that position, were slightly flattened on the bottom surface with sandpaper. The maximum deformation was selected as 25% of the thickness of the hazelnut. The force deformation curves were obtained and the maximum force in Newton at the first peak of the break was used as the measure of texture (Appendix B). To decrease deviations of the results obtained for each condition, 30–50 hazelnut samples were analyzed. Standard deviation of these measurements was standardized at 5%.

2.2.6. Moisture content measurement

For moisture content determination, whole hazelnut samples were dried in an electrical oven at 105 °C up to the establishment of constant weight (AOAC, 1984). Calculation was done by using weight of the hazelnut before it was placed into the oven and weight of the roasted hazelnut immediately after it was removed from the oven.

2.2.7. Determination of free fatty acids

Free fatty acids of the hazelnut roasted by conventional oven and microwave–infrared combination oven at the optimum points were detected by gas chromatography with a flame ionization detector (Agilent 6890, Santa Clara, CA, USA). The oil was extracted from the ground hazelnut with *n*-hexane. 10 ml of *n*-hexane was used for 1 g of ground hazelnut. The esterification of free fatty acids of extracted oil was performed by adding 100 μl of 2.0 N potassium hydroxide in methanol. The suspension was centrifuged and 1 μl of clear supernatant was directly injected into the gas chromatography. The fatty acid methyl esters were separated on a fused silica column coated with DB-23, (50%-Cyanopropyl- 50%-methylpolysiloxane). As carrier gas helium, with flow rate 36 cm/s at 50 °C and at 53 kPa was used, the injection port temperature was 250 °C and the detector temperature was 250 °C. The oven temperature was kept at 50 °C for 1 min initially, and then increased to 200 °C at a rate of 25 °C/min, then again increased to 230 °C at the rate of 3 °C/min and maintained at 230 °C for 18 min.

2.2.8. Statistical analysis and optimization

The second-order regression equations and coefficients were determined from the analysis of response surface design by using MINITAB® Release 14.1 (Minitab Inc. State College, PA, USA). As a result of applying ANOVA, only the factors affecting responses significantly were selected. Anderson and Darling normality test and Bartlett's test were performed for checking model's adequacy. The optimization of the process conditions of microwave–infrared and microwave-convective heating combination roasting was calculated by optimization tool of MATLAB Package (Version:7.4.0.278, R2007a, The MathWorks Inc., Natick, MA, USA). A constraint optimization program was written by entering the models obtained for responses L^* and a^* values, texture and moisture content. The models were maximized for moisture content and minimized for fracture force. Constraints were acquired from the L^* and a^* values of conventionally roasted hazelnut.

CHAPTER 3

RESULTS AND DISCUSSION

In the first part of the study, optimizations of microwave-infrared combination roasting were studied and in the second part, roasting conditions of hazelnut in microwave-convective heating combination oven were optimized. In the third part of the study these two roasting methods were compared.

3.1 Optimization of Roasting Conditions of Hazelnuts in Microwave-Infrared Combination Oven

The optimum hazelnut roasting conditions of microwave-infrared combination oven, being a novel technology, was determined by using Response Surface Methodology.

3.1.1 Analysis of Central Composite Design

To find the effect of microwave power (X_1), upper infrared power (X_2), lower infrared power (X_3), and time of the process (X_4) on quality parameters (L*, a*, texture and moisture content), a mathematical equation $Y=f(X_1, X_2, X_3, X_4)+\varepsilon$ was used. To approximate Y, a second order polynomial equation was assumed after realizing that a first order equation was not capable of expressing the relation (Equation 3.1);

$$Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_1^2+b_6X_2^2+b_7X_3^2+b_8X_4^2+b_9X_1X_2+b_{10}X_1X_3+ b_{11}X_1X_4+b_{12}X_2X_3+b_{13}X_2X_4+b_{14}X_3X_4+ \varepsilon \quad (3.1)$$

where b_0 is the intercept, b_1, b_2,... ,b_{14} are the coefficients, and ε is the residual error. The regression equations and coefficients were determined from the analysis of central composite design. The analysis was performed individually for all the responses. The regression models were simplified by eliminating insignificant terms. Thus, the number of terms in the regression models were reduced. Reducing the number of terms provides useful and simple models which is easier to work with. The models were reduced manually by looking at the p-value of each coefficient. The coefficient with the highest p-value was eliminated first, then elimination was continued until only significant terms remained. Before proceeding with exploration and optimization of the models, it was necessary to check whether they were adequate to fit. The residuals from the least squares fit, defined by $\varepsilon_i = y_i - \hat{y}_i$, i=1, 2,…, n, play an important role in judging model adequacy. The residuals were assumed to be normally distributed with a constant variance. Normal probability curves of standardized residuals were drawn and the figures seemed to be linear but in order to be sure about the normality, Anderson and Darling Normality test was conducted. Normality test generates a normal probability plot and performs a hypothesis test to examine whether or not the observations follow a normal distribution. For the normality test, the hypotheses are,

H_0: data follow a normal distribution
H_1: data do not follow a normal distribution

The p-values displayed on the graph were greater than the significance level of 0.05 which showed that data were normally distributed (Appendix D).

For the assumption of constant variance, residuals versus fitted values graphs were drawn. No pattern was observed in these graphs. However, in order to be sure about the constant variability, Bartlett's Test was used to perform hypothesis tests for equality or homogeneity of variance. Since the residuals were normally distributed, there was no problem of using this test. The hypotheses of Bartlett's Test are,

H_0: data have equal variance
H_1: data do not have equal variance

The p-values on the graph were greater than reasonable choice of α=0.05, so we fail to reject the null hypothesis of the variances being equal (Appendix D).

After these tests, it was concluded that the residuals were normally distributed with constant variance. The final models with adjusted coefficient of determination (R^2_{adj}) are given in Table 3.1. The coefficient of determination was quite high for all of the quality parameters. ANOVA tables and regression coefficients are given in detail in Appendix C.

Table 3.1 Regression equations for roasted hazelnuts in microwave-infrared combination oven

Quality Parameter	Equation	R^2_{adj}
L* value	$Y_1 = 65.6332 - 3.27629X_1^{****} - 1.57039X_2^{***} - 1.20355X_3^{**} - 2.77034X_4^{****} - 2.60224X_1^{2****} - 0.977237X_4^{2**} - 2.2205X_1X_2^{***} - 2.34283X_2X_4^{***}$;	0.88
a* value	$Y_2 = 14.2337 + 2.19797X_1^{****} + 1.58857X_2^{****} + 0.176584X_3^{*} + 1.41392X_4^{****} + 0.271334X_1^{2*} + 0.467093X_4^{2*}$;	0.87
Fracture Force (N)	$Y_3 = 42.1593 - 6.29307X_1^{****} - 4.99526X_2^{****} - 1.5716X_3 + 2.5842X_4^{*} + 1.77275X_2^{2*} + 1.76414X_3^{2*} - 3.07594X_1X_2^{*} + 3.10211X_2X_3^{*} - 3{,}74642X_3X_4^{**}$;	0.77
Moisture Content (%)	$Y_4 = 1.44565 - 0.46378X_1^{****} - 0.300785X_2^{****} - 0.199925X_3^{***} - 0.41899X_4^{****} - 0.150939X_3^{2***} + 0.182540X_1X_2^{**} - 0.242470X_1X_3^{***} + 0.151965X_1X_4^{*}$;	0.93

**** Significant at 0.01% level, *** Significant at 0.1% level, ** Significant at 1% level, *Significant at 5% level

3.1.2. Effects of Microwave-Infrared Roasting on Color Parameters of Hazelnuts

It can be seen from the model equation that *a** and *L** values changed with microwave power, upper and lower infrared power and roasting time significantly (Table 3.1). Since none of the factors were significantly affecting b* value, it was excluded from the study (Appendix C). The value of a* representing 'greenness' or

’redness’ ranging from -60 to +60, increased as microwave power, and roasting time increased (Figure 3.1). The increase in a* value exhibits the reddish color. The other important parameter that reveals the color of hazelnut is L* value. L* value, representing ‘lightness’ from zero (black) to 100 (white), significantly decreased as microwave and roasting time increased (Figure 3.2). The decrease in *L** value exhibits the darker color of hazelnut due to the formation of brown pigments through Maillard reactions. As the microwave power and roasting time increased, hazelnut kernel was interacted with microwaves more. More heat was generated inside the hazelnut, leading to an increase in internal temperature for longer times. Time and temperature relation is important in Maillard reactions. An increase in temperature for longer times leads to an increase of the reactivity between the sugar and the amino group (Martins et al., 2001). Thus, the effect of microwave power for longer roasting times was more significant than for shorter times. The curvature contour of the graphs indicated that the squares of microwave power and roasting time significantly affected *a** and *L** values.

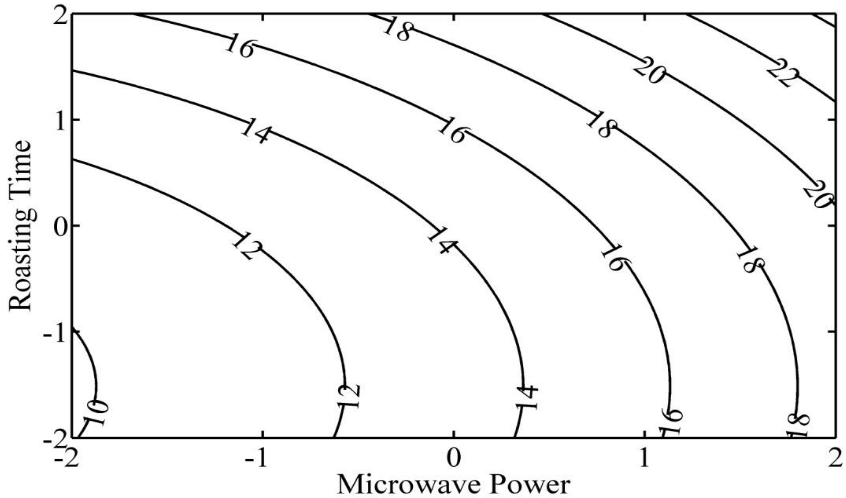


Figure 3.1 Variation of a* value with microwave power (X_1) and roasting time (X_4) when X_2 and X_3= 0.

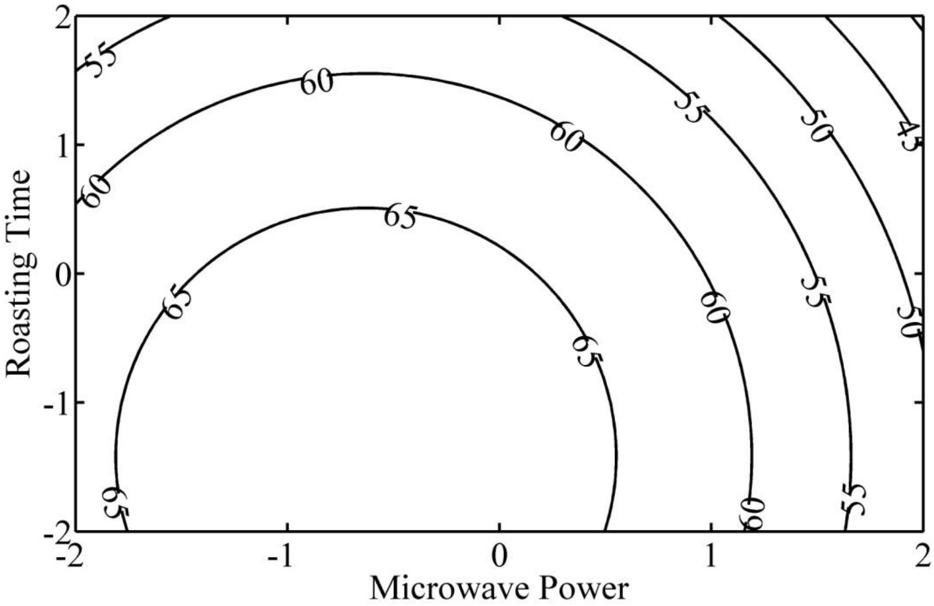


Figure 3.2 Variation of L* value with microwave power (X1) and roasting time (X4) when X2 and X3=0.

As upper and lower infrared powers increased, *a** value increased (Figure 3.3) but *L** value decreased (Figure 3.4), since more near infrared radiation was applied to hazelnut from the top and the bottom leading to more browning reactions. Moreover, infrared heating is known to provide low penetration depth and concentrate radiation at the surface, so the surface temperature can reach the required values for browning. However, upper infrared power was found to be more significant than lower infrared power, since the change in *a** and *L** values was more distinctive when upper infrared power increased as compared to lower infrared power (Table 3.1 and Figure 3.3 and 3.4). It was previously shown that as temperature and roasting time increased similar results were obtained in *L** and *a** values during conventional roasting of hazelnuts (Ozdemir and Devres, 2000a, Ozdemir and Devres, 2000b and Saklar et al., 2001).

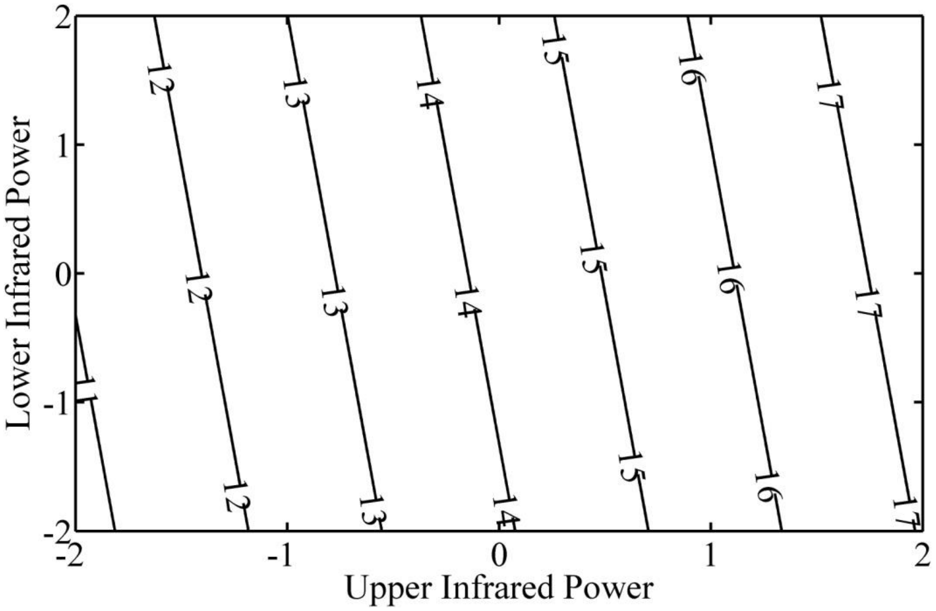


Figure 3.3 Variation of a* value with upper infrared power (X_2) and lower infrared Power (X_3) when X_1 and X_4=0.

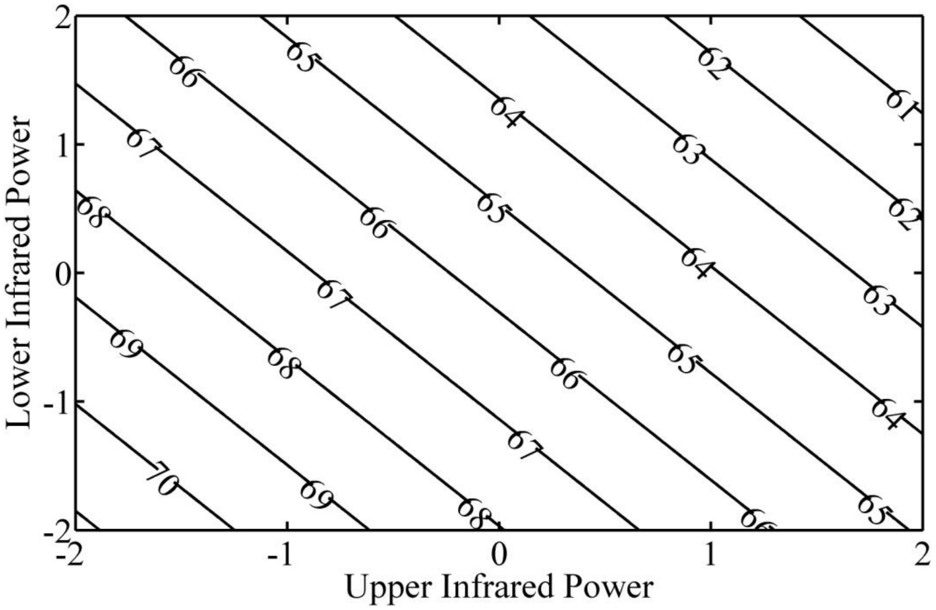


Figure 3.4 Variation of L* value with upper infrared power (X_2) and lower infrared power (X_3) when X_1 and X_4=0.

3.1.3. Effects of Microwave-Infrared Roasting on Texture of Hazelnuts

The maximum force at the first fracture point named as fracture force was used to reflect the textural properties of hazelnut. Microwave power and upper infrared power were found to be more significant than roasting time and lower infrared power (Table 3.1) on affecting the texture of hazelnut. As microwave power and upper infrared powers increased, the force needed to break a hazelnut kernel decreased (Figure 3.5.). Microwave power was more significant than upper infrared power on affecting fracture force, since there was much more decrease in fracture force when microwave power increased as compared to upper infrared power. Because of the interaction between upper infrared power and microwave power, the effect of microwave power became more significant for higher upper infrared powers.

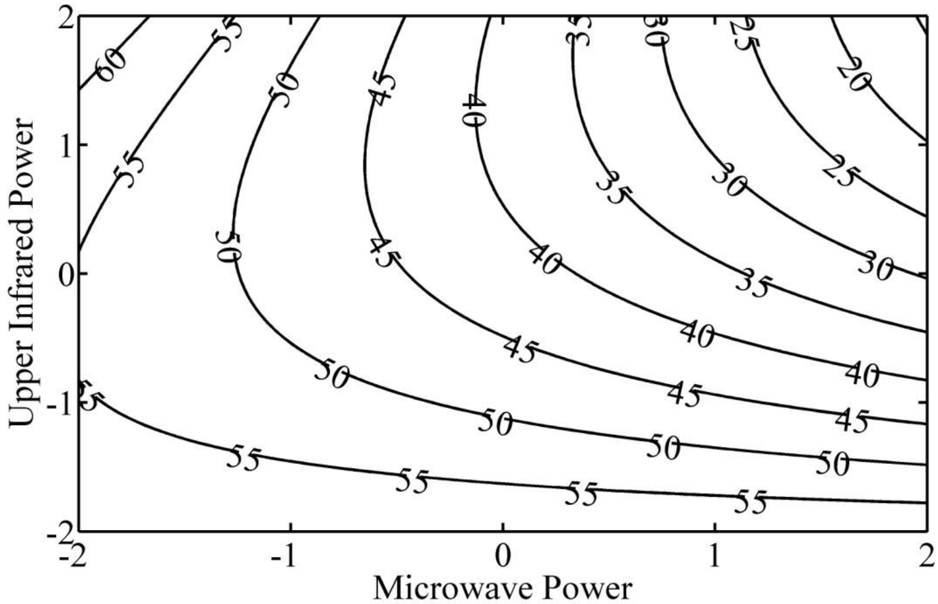


Figure 3.5 Variation of fracture force with microwave power (X_1) and upper infrared power (X_2) when X_3 and X_4=0.

The increase in roasting time increased the fracture force (Figure 3.6) which is in contradiction with the study of conventional roasting (Demir and Cronin, 2004). This may be explained by the difference between the mechanisms of microwave combined with infrared heating and conventional heating. In microwave–infrared roasting, heat is generated inside the hazelnut by microwaves leading to an increase in temperature. At the same time, near infrared radiation penetrates from surface to the interior. The unique textural changes of hazelnut upon microwave–infrared roasting may be due to the specific interaction of microwaves with hazelnut protein. Up to 50% lower infrared power, force at the first fracture point was decreased. However, for the higher values of lower infrared powers fracture force increased with increase in infrared power since the interaction of roasting time and lower infrared power became more distinctive.

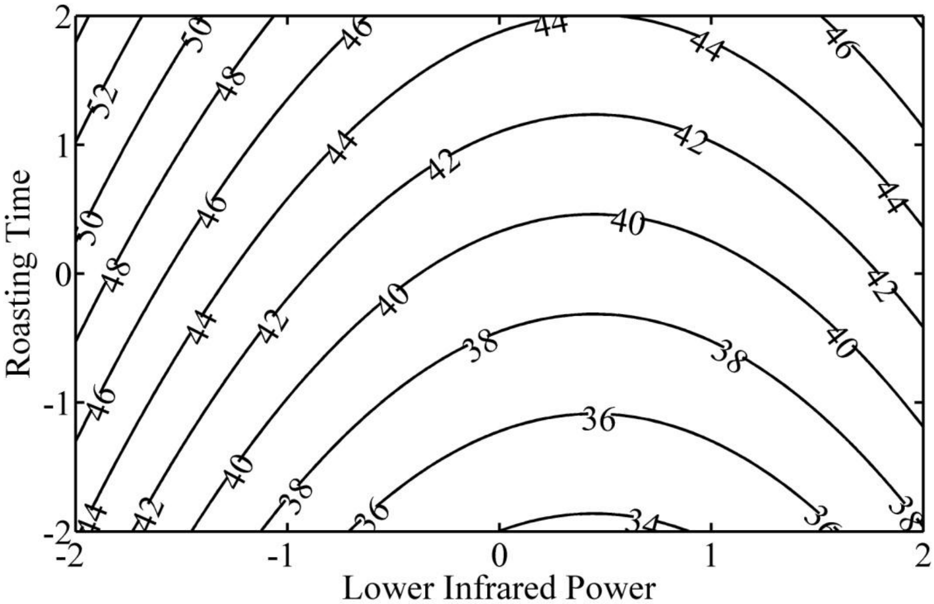


Figure 3.6 Variation of fracture force with lower infrared power (X_3) and roasting time (X_4) when X_1 and X_2=0.

3.1.4. Effects of Microwave-Infrared Roasting on Moisture Content of Hazelnuts

During roasting process, hazelnuts undergo several changes including moisture loss. Moisture content of hazelnuts decreased as microwave power and upper infrared powers increased (Figure 3.7). When microwave power increases, more interior pressure and concentration gradients are developed (Datta, 1990 and Demirekler et al., 2004). The high pressure and concentration gradients in hazelnut might lead to high rate of removal of moisture from the sample. Thus, higher moisture loss was observed with increase in microwave power (Figure 3.7 and Table 3.1). Similar effect of microwave power levels on weight loss of bread samples during baking was also observed by other researchers (Keskin et al., 2004). It was also observed that the use of upper infrared prevented the sogginess problem of microwave heating. Thus, water in unbound form might have been removed from hazelnut quickly, even at lower powers of microwave and upper infrared. It was also observed that the rate of moisture loss was lower, as microwave power and upper infrared power increased which can be explained by the increase in the resistance of moisture removal at these conditions. Moisture content decreased during roasting (Figure 3.8). Lower infrared power was not as efficient as roasting time in affecting moisture content. The effect of lower infrared power on moisture content was found to be insignificant by other researchers also (Demirekler et al., 2004; Sevimli et al., 2005). Since the lower infrared is placed under the turntable, its effect on moisture content became insignificant.

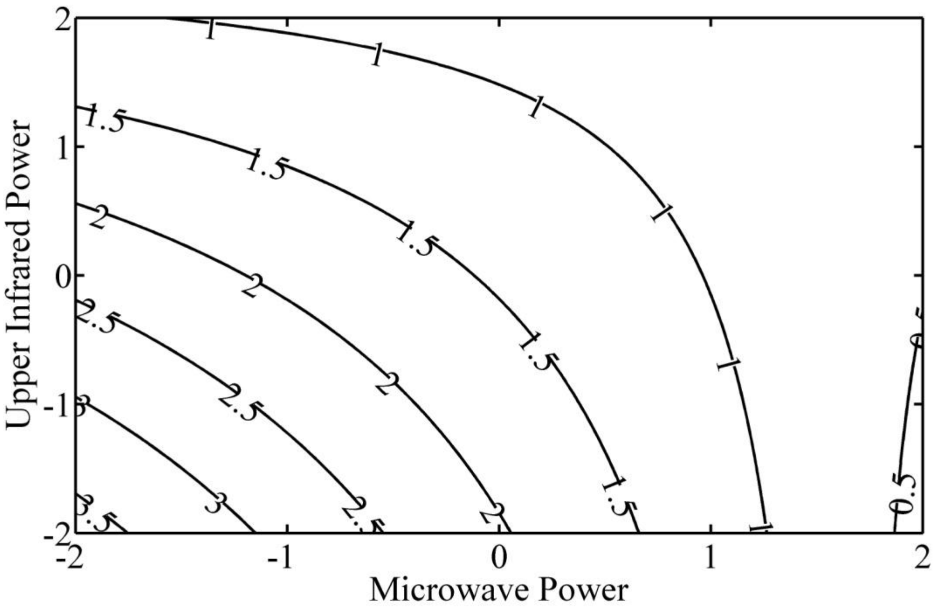


Figure 3.7 Variation of moisture content with microwave power (X_1) and upper infrared power (X_2) when X_3 and X_4=0.

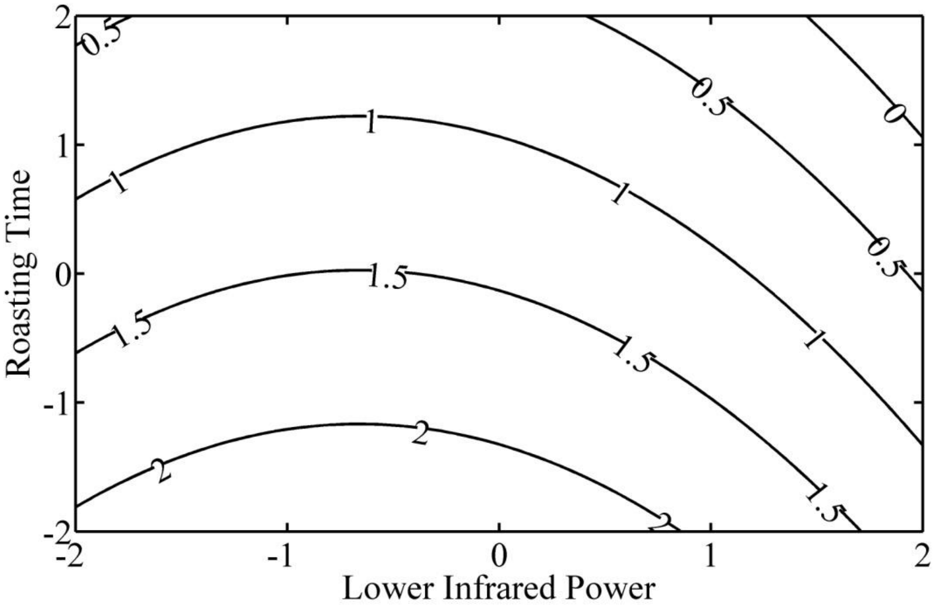


Figure 3.8 Variation of moisture content with lower infrared power (X_3) and roasting time (X_4) when X_1 and X_2=0.

3.1.4. Determination of the Optimum Point

In order to find the optimum point, a Matlab program was written to minimize fracture force and maximize moisture content of microwave–infrared roasted hazelnuts (Appendix E). Minimization of fracture force to determine the optimum point was necessary since it shows the brittleness of the hazelnuts. Since there is no standard value for color of roasted hazelnuts in literature, color values (L* and a* values) of conventionally roasted hazelnut were accepted as standard and used as constraints (Equations (3.2) and (3.3)). These constraints defined a set of lower and upper limits on the design variables, so that the solution was around these range.

$$46 \leq L^* \leq 52 \tag{3.2}$$

$$17 \leq a^* \leq 19 \tag{3.3}$$

The corresponding coded and rounded uncoded values of the optimum point calculated are given in Table 3.2. The optimum point found was rounded since the microwave–infrared combination oven could not operate at the midpoints.

Table 3.2 The optimum coded and rounded uncoded values of the operating conditions of roasting of hazelnut in the microwave-infrared oven.

Factors	Optimum coded value	Optimum rounded uncoded value
Microwave power	1.944	90% (613,8 Watt)
Upper infrared power	0.500	60% (1800 Watt)
Lower infrared power	-1.459	20% (300 Watt)
Time of the roasting process	-1.548	2.5 min

In addition to color, texture and moisture content, fatty acid compositions of hazelnuts roasted in conventional oven and at the optimum roasting condition of microwave-infrared combination oven were determined and given in Table 3.3.

As can be seen from Table 3.3, hazelnuts roasted in microwave– infrared combination oven at the optimum condition of 2.5 min of roasting at 60% upper infrared power, 20% lower infrared power, and 90% microwave power were comparable in quality in terms of textural characteristic, moisture content and color with conventionally roasted ones. Moreover, the roasting time of the hazelnuts was reduced by 87.5%.

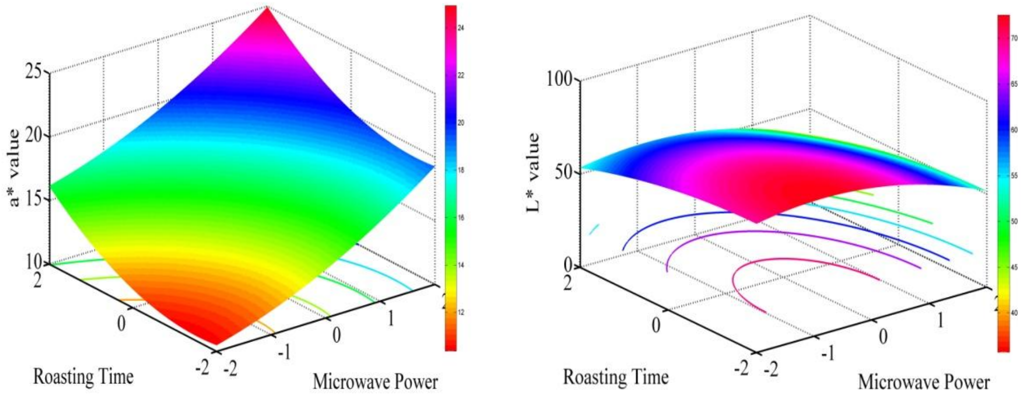
The fatty acid composition of conventionally roasted hazelnuts was found to be not significantly different from the ones roasted in the microwave–infrared combination oven (Table 3.3). The fatty acid composition can be an indicator of the stability and degradation rates of hazelnut and is also very important in terms of the nutritional value.

Table 3.3 Response values and fatty acid composition for hazelnuts roasted in microwave-infrared combination oven and control hazelnuts roasted in conventional oven

	Microwave-infrared oven roasting at the optimum point	Conventional oven roasting
L* value	50.26	52.17
a* value	17.15	18.03
Fracture force (N)	22.16	21.53
Moisture content (%)	1.39	1.22
Oleic acid (C18:1) (%)	76.44	78.80
Linoleic acid (C18:2) (%)	13.00	10.50
Palmitic acid(C16:0) (%)	5.88	5.87
Stearic acid(C18:0) (%)	3.11	3.27

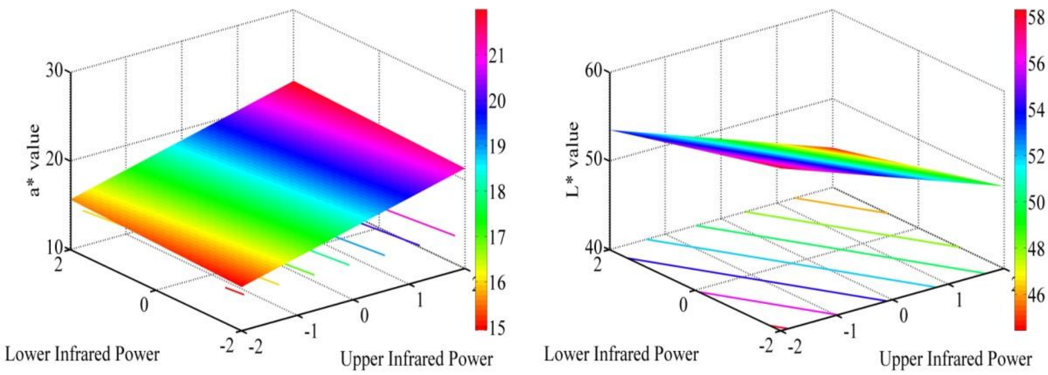
The responses for the calculated optimum point were shown in 3-D plots. Figure 3.9(a) and Figure 3.9(b) show the effect of microwave power with respect to roasting time on color, mainly a* and L* values of hazelnuts, respectively. As can be seen from these figures, the increase in microwave power and roasting time, increased a* value, whereas increase in microwave power and roasting time, decreased L* value significantly at the optimum point of %60 and %20 for upper and lower infrared powers, respectively. Figure 3.10(a) and Figure 3.10(b) show the response surface for the effect of upper and lower infrared powers on a* and L* values of hazelnuts at the optimum conditions of 2.5 min roasting time and %90 microwave power. As can be seen from these figures, the increase in upper and lower infrared powers, increased a* value but decreased L* value of hazelnuts. Since the interactions and the squares of upper and lower infrared powers were not significant, straight surfaces were obtained. However, the effect of upper infrared power was more significant on effecting color parameters as compared to lower infrared power.

Fracture force of hazelnuts was found to be affected by microwave power, upper infrared power and roasting time significantly. Figure 3.11(a) and Figure 3.11(b) show the effect of microwave power with respect to roasting time and microwave power with respect to upper infrared power on fracture force, respectively. As can be seen on Figure 3.11(a), the increase in microwave power decreased fracture force while the increase in roasting time increased fracture force at the optimum operating conditions of upper (60%) and lower infrared powers (20%). Figure 3.11(b) showed how fracture force decreased as upper infrared power increased at the optimum operating conditions of lower infrared power (20%) for 2.5 roasting time.



(a) (b)

Figure 3.9 Response surfaces showing the effect of microwave power and roasting time for (a) a* value and (b) L* values of hazelnuts at the optimum conditions of upper (60%) and lower infrared (20%) powers. (X_2=0.5 and X_3=-1.5)



(a) (b)

Figure 3.10 Response surfaces showing the effect of upper and lower infrared powers for (a) a* value and (b) L* values of hazelnuts at the optimum conditions of microwave power (90%) and for 2.5 min roasting time (X_1=2 and X_4=-1.5).

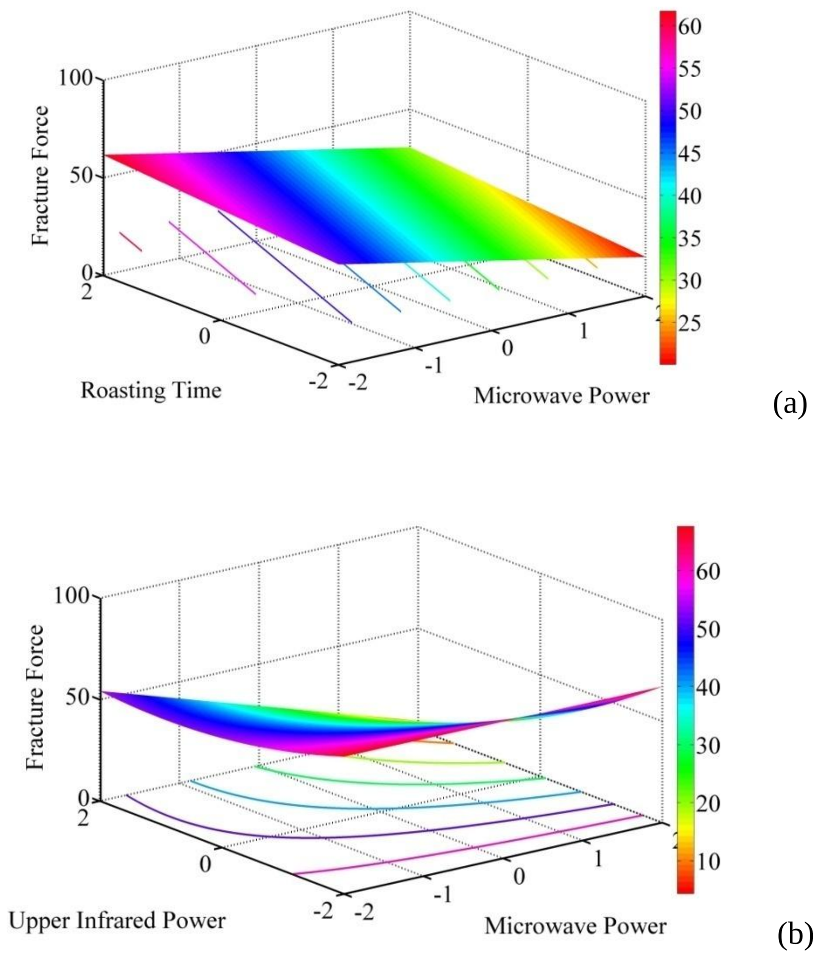
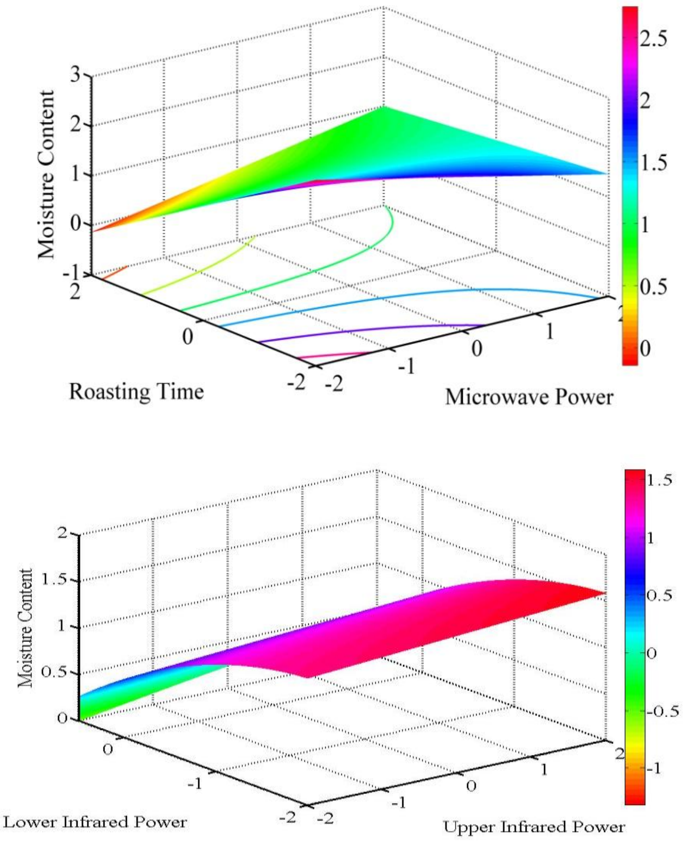


Figure 3.11 Response surfaces for fracture force showing the effect of (a) microwave power and roasting time (X_2=0.5 and X_3=-1.5), (b) microwave power and upper infrared power (X_3=-1.5 and X_4=-1.5).

Microwave power, upper, lower infrared powers and roasting time was found to affect moisture content of hazelnuts. Figure 3.12(a) shows the effect of microwave power and roasting time at the optimum upper and lower infrared powers (60% and 20% respectively) on moisture content in 3-D configuration. Figure 3.12(a) clearly shows that the increase in microwave power and roasting time decreased moisture content. Keskin et al. (2004) also obtained similar effects of microwave power and time on moisture content of breads. Figure 3.12(b) exhibits the change of moisture content with respect to upper and lower infrared powers (at X_1=0.5 and X_4=-1.5). Although the upper infrared power was found to be less effective on moisture content, decrease in moisture content was observed as upper infrared power increased. Moisture content decreased rapidly as lower infrared power increased (Figure 3.12(b).



(a)

(b)

Figure 3.12 Response surfaces for moisture content showing the effect of (a) microwave power and roasting time (X_2=0.5 and X_3=-1.5), (b) upper infrared power and lower infrared power (X_1=2 and X_4=-1.5)

In order to compare the microwave-infrared roasting models obtained for a* value, L* value, fracture force and moisture content with the experimental results, these dependent variables at different experimental conditions were calculated using the models. These predicted values were compared with the experimental results in Figure 3.13. The coefficient of determination showing the relationship between predicted and experimental data were quite high. This was a good indication that the regression models were appropriate and powerful for the responses; a*, L*, fracture force and moisture content of hazelnuts.

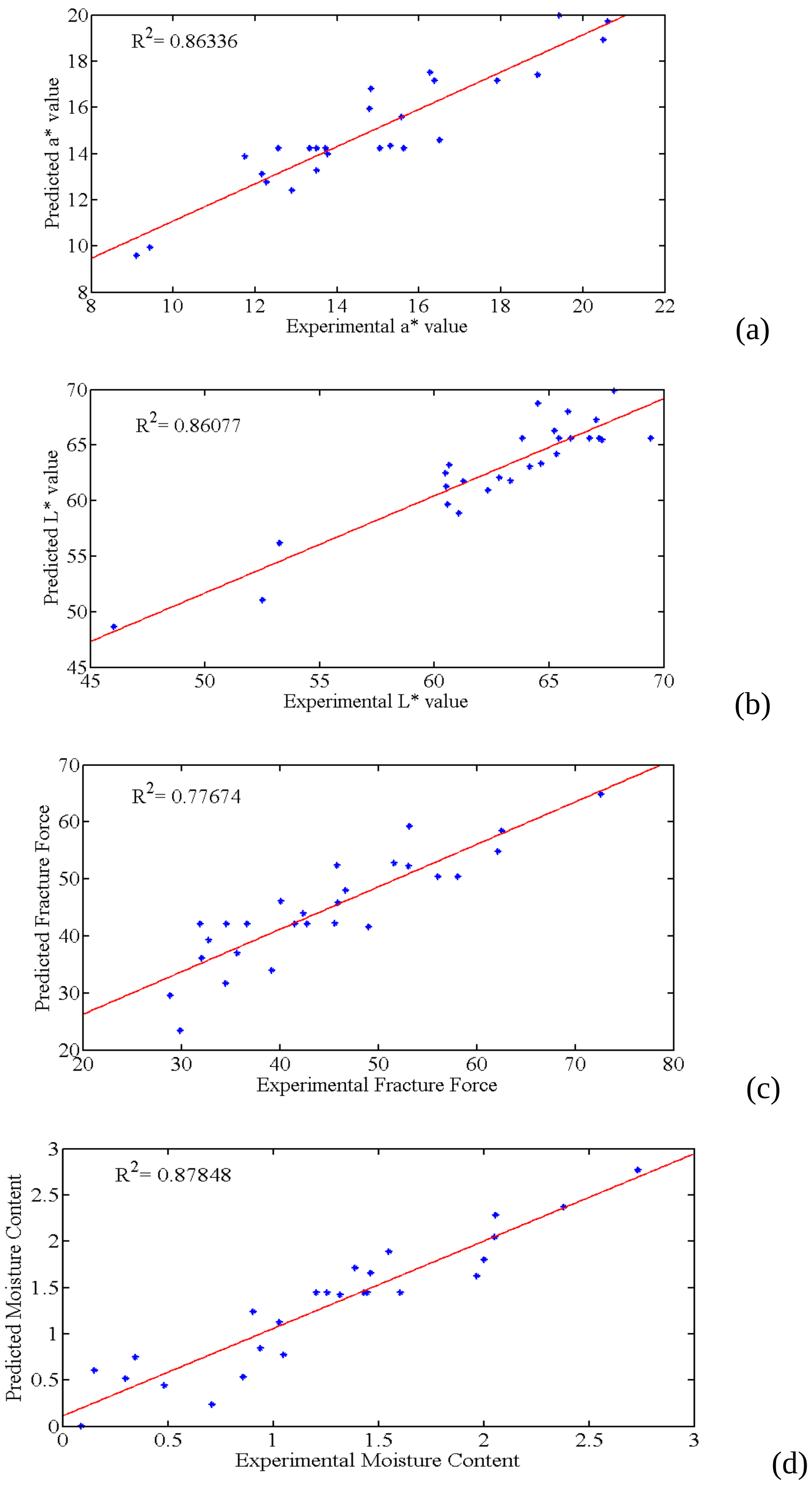


Figure 3.13 Comparison of predicted and experimental values of dependent variables for hazelnuts (a) a* value, (b) L* value, (c) fracture force, (d) moisture content

3.2 Optimization of Roasting Conditions of Hazelnuts in Microwave-Convective Heating Combination Oven

The optimum hazelnut roasting conditions of microwave-convective heating combination oven was determined by using Response Surface Methodology.

3.2.1 Analysis of Box-Behnken Design

The effects of microwave power (X_1), air temperature (X_2), and time of roasting (X_3) on quality parameters of L* value, a* value, texture and moisture content were modeled using a mathematical equation $Y=f(X_1, X_2, X_3)+\varepsilon$.

To approximate Y, a second order polynomial equation was assumed (Equation 3.4);

$$Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_4X_1^2+b_5X_2^2+b_6X_3^2+b_7X_1X_2+b_8X_1X_3+b_9X_2X_3+\varepsilon \quad (3.4)$$

The regression equations and coefficients were determined from the analysis of Box-Behnken Design. Anderson and Darling Normality test and Bartlett's test were used for the residual analysis in the same way of Central Composite Design (Appendix D). After these tests, it was concluded that the residuals were normally distributed with constant variance. The final models with adjusted coefficient of determination (R^2_{adj}) are given in Table 3.4. The coefficient of determination was acceptable for all of the quality parameters. ANOVA tables and regression coefficients are given in detail in Appendix C.

Table 3.4 Regression equations for roasted hazelnuts in microwave-convective heating combination oven.

Quality Parameter	Equation	R^2_{adj}
L* value	Y_1=56.8267-0.9708X_1-3.8708X_2****-2.4417X_3** -3.1583X_1X_2**-3.8333 X_2X_3**;	0.83
a* value	Y_2=13.307+2.337X_2****+2.279X_3***+2.142X_2X_3**;	0.86
Fracture Force (N)	Y_3=22.155-11.218X_2**-9.906X_3*+10.531 X_2^2* +21.18X_3^2**-9.276X_1X_2;	0.80
Moisture Content (%)	Y_4=2.3492-1.0676X_2**-1.1273X_3***+0.9446X_3^2* -0.8572X_2X_3*;	0.80

**** Significant at %0.01 level, *** Significant at %0.1 level, ** Significant at %1 level, * Significant at %5 level

3.2.2. Effects of Microwave-Convective Heating Combination Roasting on Color Parameters of Hazelnuts

The model equations clearly showed that microwave power had no effect whereas air temperature and roasting time had leading roles on influencing color parameters, a* and L* value. Since microwave power does not significantly affect color parameters, it was excluded from the model a* value. Since the interaction of microwave power with air temperature was significant on affecting L* value (Table 3.4), microwave power was not excluded from the model. The surface temperature of the product could not reach the required values for browning even if the maximum microwave power was selected in microwave baking (Sakiyan, 2007; Keskin, 2003; Sevimli et al., 2005). Moreover, the experimental design covered high temperature levels (90-210°C). High temperatures might suppress the effect of microwave power which had the maximum value of 210W. The effect of microwave power on color values was also found to be insignificant for microwave-infrared roasting for short times (Figure 3.1 and 3.2). However, as roasting time increased the effect of microwave power increased. This may be explained by the interaction of microwaves and infrared for long processing times.

According to Table 3.4, Figures 3.14 and 3.15, a* value increased but L* value decreased as air temperature and roasting time increased. This result seemed reasonable since decrease in L* value displays darker color and increase in a* value displays reddish color of hazelnuts. Roasting hazelnuts at high temperatures for longer times increase the rate of Maillard reactions leading to darker and more reddish hazelnuts. As stated before in discussing the effects of microwave-infrared roasting on color parameters of hazelnuts, an increase in temperature for longer times leads to an increase of the reactivity between the sugar and the amino group (Martins et al., 2001). Thus, the effect of air temperature for longer roasting times was more significant than for shorter times. The curvature contour of the graphs indicated that the squares and interactions of air temperature and roasting time significantly affected *a** and *L** values.

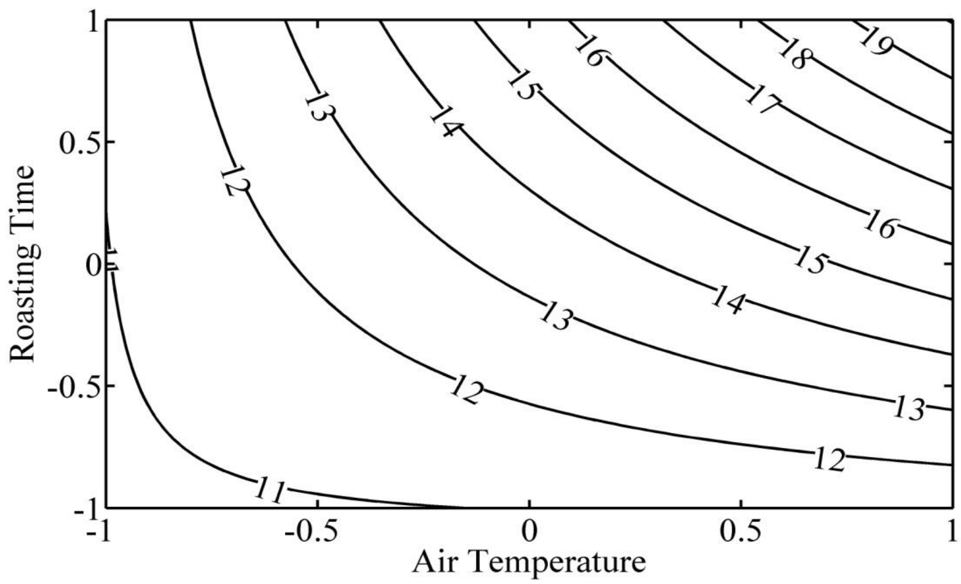


Figure 3.14 Variation of a* value with air temperature (X_2) and roasting time (X_3) when X_1=0.

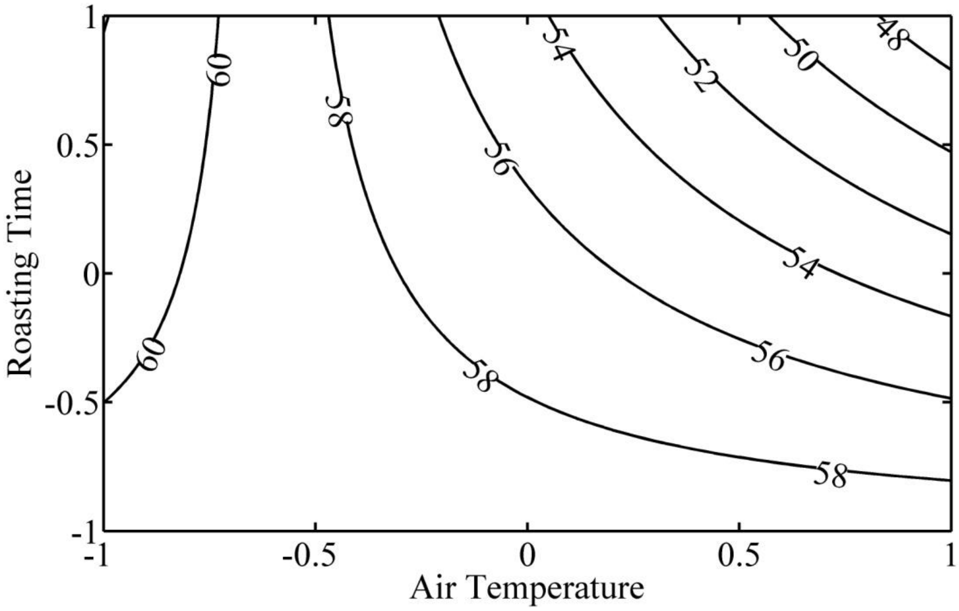


Figure 3.15 Variation of L* value with air temperature (X_2) and roasting time (X_3) when X_1=0.

3.2.3. Effects of Microwave-Convective Heating Combination Roasting on Texture of Hazelnuts

The regression equation of fracture force disclosed that the most significant factor was air temperature (Table 3.4). Since microwave power was not a significant factor on affecting fracture force, it was excluded from the regression model. The effect of temperature, covering high values, and roasting time may be the primary reasons of the change in fracture force. As air temperature and roasting time increased, the fracture force of hazelnuts decreased (Figure 3.16). Similar results were obtained by other researchers (Saklar et al., 1999; Demir and Cronin, 2004; Kahyaoğlu and Kaya, 2006). A minimum value of fracture force was observed at the high values of temperature and time. Fracture force decreased significantly for the higher values of air temperature and roasting time.

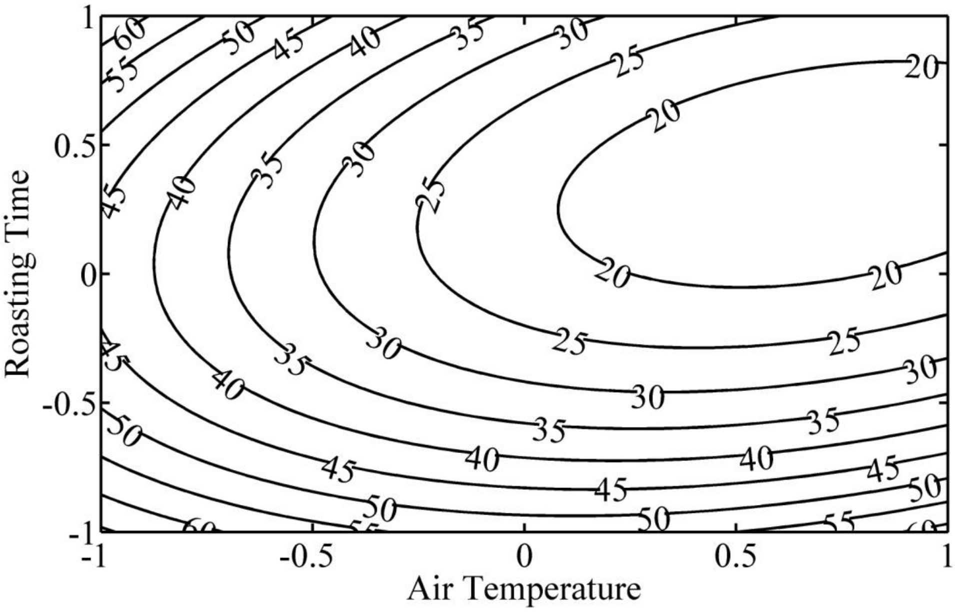


Figure 3.16 Variation of fracture force with air temperature(X_2) and roasting time (X_3) when (X_1)=0.

3.2.4. Effects of Microwave-Convective Heating Combination Roasting on Moisture Content of Hazelnuts

Air temperature and roasting time seemed to be much more significant than microwave power on effecting moisture content of microwave-convective heating combination roasting of hazelnuts, thus microwave power was not included in the model (Table 3.4). As air temperature and roasting time increased, removal of moisture increased (Figure 3.17). Figure 3.17 clearly showed that the effect of roasting temperature increased for longer roasting times. Ozdemir (2001) also observed that higher roasting temperature and time resulted in higher moisture loss of hazelnuts. Kahyaoğlu and Kaya (2006) showed that the increase in roasting time and air temperature decreased moisture content of sesame seeds, significantly.

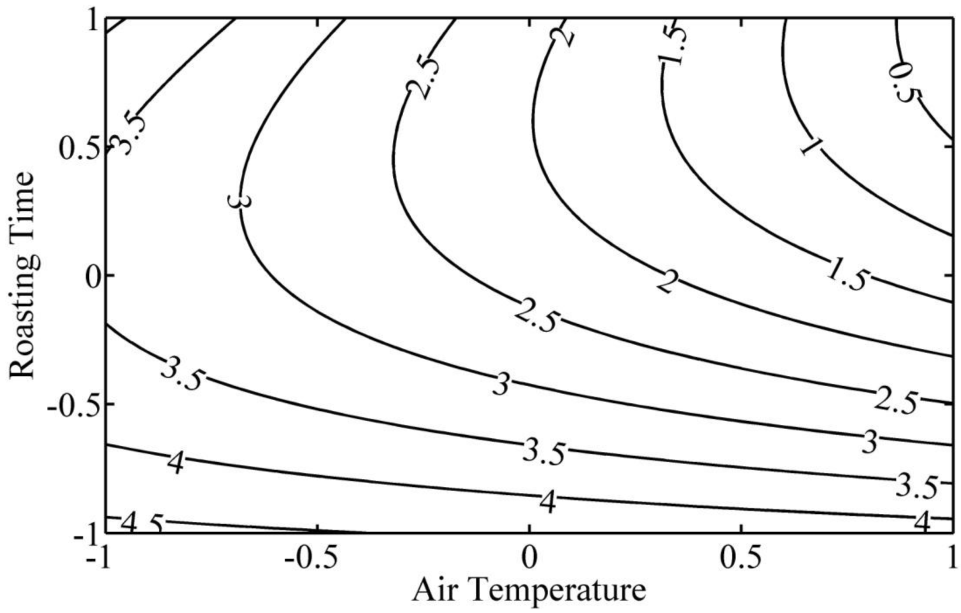


Figure 3.17 Variation of moisture content with air temperature(X_2) and roasting time (X_3) when (X_1)=0.

3.2.5. Determination of the Optimum Point

In order to determine the optimum point of operating conditions in microwave-convective heating combination oven, a Matlab program was written which minimizes fracture force and maximizes moisture content of hazelnut (Appendix E). Matlab program was similar with the program written for optimization of microwave-infrared roasting. Microwave-infrared optimization program had to be modified since microwave-convective heating combination roasting had three factors (microwave power, air temperature, and roasting time). The same constraints of the optimization of microwave-infrared roasting were used which were the accepted color parameters (a* and L* values) of conventionally roasted hazelnuts. These constraints defined a set of lower and upper limits on the design variables, so that the solution was around these range.

$$46 \leq L^* \leq 52 \qquad (3.5)$$

$$17 \leq a^* \leq 19 \qquad (3.6)$$

Table 3.5 The optimum coded and rounded uncoded values of the operating conditions of roasting of hazelnut in the microwave-convective heating combination oven.

Factors	Optimum coded value	Optimum rounded uncoded value
Microwave power	0.02	140 W
Air Temperature	0.05	150ºC
Roasting Time	0.50	20 min

The corresponding coded and rounded uncoded values of the optimum point calculated are given in Table 3.5. The optimum point found was rounded since the microwave–convective heating combination oven could not operate at the midpoints.

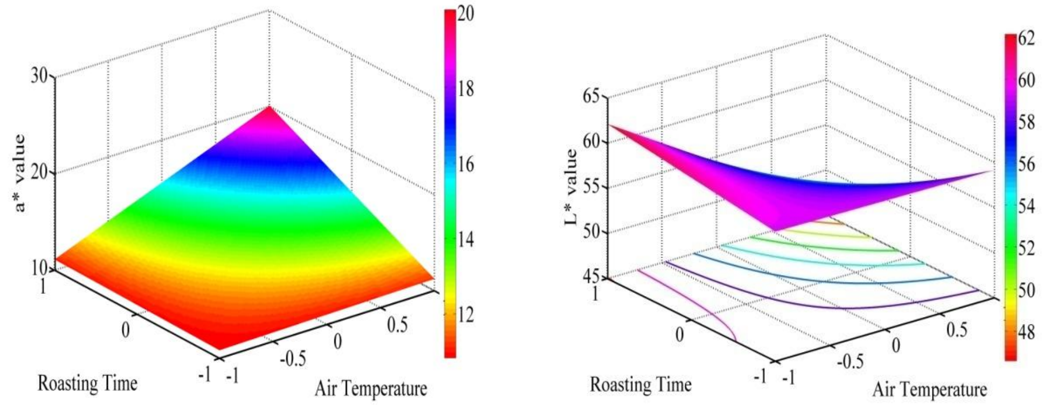
Table 3.6 Response values for hazelnuts roasted in microwave-convective heating combination oven and control hazelnuts roasted in conventional oven

	Microwave-convective heating roasting at the optimum point	Conventional oven roasting
L* value	55.45	52.17
a* value	14.45	18.03
Fracture force (N)	21.29	21.53
Moisture content (%)	1.97	1.22

As can be seen from Table 3.6, hazelnuts roasted in microwave–convective heating combination oven at the optimum condition of roasting at 140 W microwave power and at 150ºC air temperature for 20 min were comparable in quality in terms of textural characteristic, moisture content and color with conventionally roasted ones. Optimum roasting time in microwave-convective heating combination and conventional ovens were found to be the same. This result is not surprising since the effect of microwave effect on roasting in microwave-convective heating combination oven is insignificant.

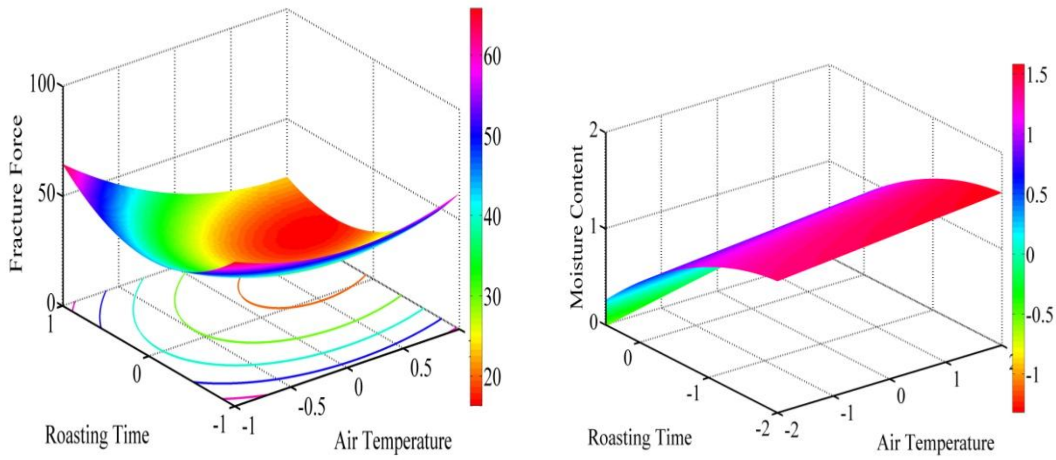
The responses for the calculated optimum point were shown in 3-D plots. The independent variables which was found to be effective on the factors were chosen, thus microwave power was ignored. Figure 3.18(a) and Figure 3.18(b) show the effect of air temperature with respect to roasting time on a* and L* values of hazelnuts at the optimum condition of microwave power (X_1=0.02), respectively. These figures showed that the increase in air temperature and roasting time increased a* value and decreased L* value. Ozdemir and Devres (2000a and 2000b), Saklar et al. (2001) also found that *L** value decreased and *a** value increased during conventional roasting of hazelnuts as temperature and roasting time increased.

Figure 3.19(a) demonstrated the effect of air temperature with respect to roasting time at the optimum operating condition of microwave power on fracture force. It was clear that as air temperature and roasting time increased force needed to break the hazelnut kernel decreased (Figure 3.19(a)). Minimum fracture force can be seen at the red parts of the graph. Minimum fracture force was needed in determination of optimum operating roasting conditions, thus calculated optimum point was seen in the area of red parts. Figure 3.19(b) showed clear views of the effect of roasting time and air temperature. According to this graph, the increase in air temperature and roasting time caused hazelnuts to lose more moisture.



(a) (b)

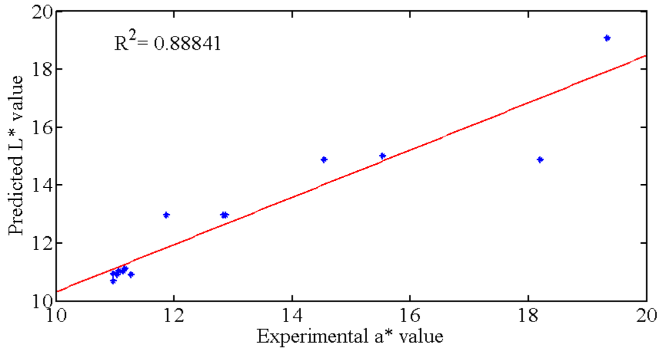
Figure 3.18 Response surfaces showing the effect air temperatures and roasting time, (a) for a* value, (b) for L* value.



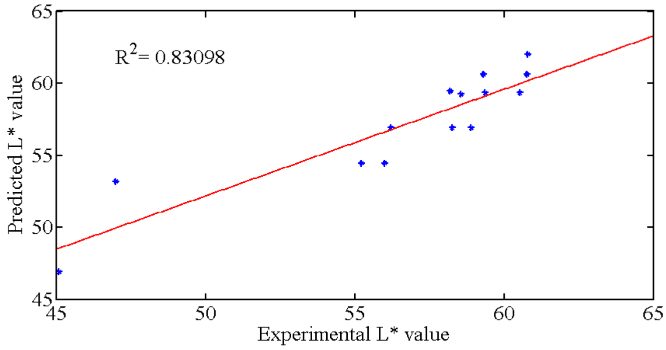
(a) (b)

Figure 3.19 Response surfaces showing the effect of air temperature and roasting time for fracture force showing the effect of (a) for fracture force (X_1=0.02), (b) for moisture content (X_1=0.02).

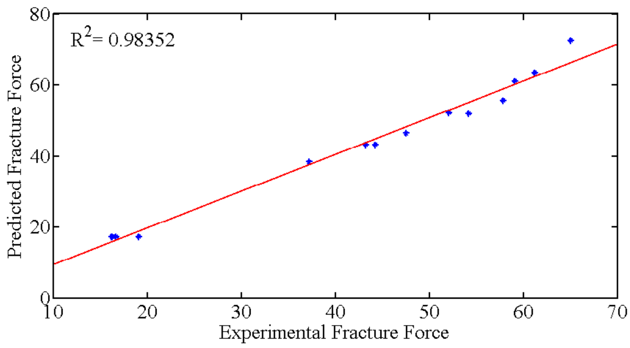
Models obtained for a* value, L* value, fracture force and moisture content of hazelnuts roasted in microwave-convective heating combination oven were compared with the experimental results. As can be seen in Figure 3.20(a-d), the coefficient of determination showing the relationship between predicted and experimental data were quite high. This was a good indication that the regression models were appropriate and powerful for the responses; a*, L*, fracture force and moisture content.



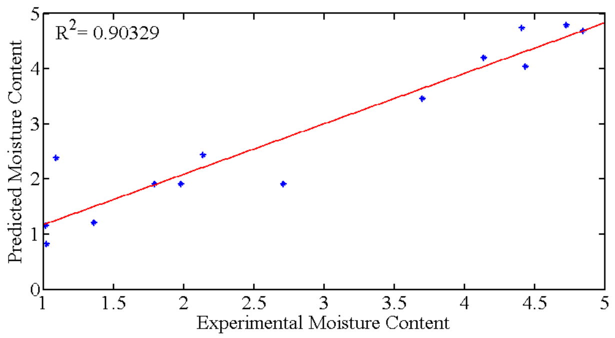
(a)



(b)



(c)



(d)

Figure 3.20 Comparison of predicted and experimental values of dependent variables for hazelnuts (a) a* value, (b) L* value, (c) fracture force, (d) moisture content

3.3 Comparison of Microwave-Infrared Roasting, Microwave-Convective Heating Combination Roasting with Conventional Roasting

Table 3.7 showed that the quality parameters of hazelnuts roasted in microwave-infrared, microwave-convective heating combination ovens were comparable with hazelnuts roasted in conventional oven. Hazelnuts roasted at 614W microwave power, at 1800W upper infrared power, at 300W lower infrared power for 2.5 min in microwave-infrared combination oven; roasted at 140W, at 150°C for 20 min in microwave-convective heating combination oven were found to be comparable with hazelnuts roasted at 150°C for 20 min in electrical conventional oven. Conventional roasting time was reduced by 87.5%, when hazelnuts were roasted in microwave-infrared combination oven. However, microwave-convective heating combination oven did not reduce the conventional roasting time.

Table 3.7 Quality parameters of hazelnut roasted in different ovens at the optimum point

	Microwave-infrared combination oven	Microwave-convective heating combination oven	Conventional oven
L* value	50.26	55.45	52.17
a* value	17.15	14.45	18.03
Fracture force (N)	22.16	21.29	21.53
Moisture content (%)	1.39	1.97	1.22

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Response surface methodology was successfully applied in order to determine the optimum roasting conditions in both microwave-infrared and microwave-convective heating combination ovens. The high coefficient of determination of the regression models for all of the responses showed that the models fitted the data well for both roasting methods. For roasting of hazelnuts in microwave-infrared combination oven, microwave power, upper and lower infrared powers and roasting time were found to be significant on affecting L* value, a* value, fracture force and roasting time. However, lower infrared power was found to be less significant than the other independent variables. As microwave power, upper and lower infrared powers, and roasting time increased, a* value increased but L* value, force needed to break hazelnut kernel and moisture content of hazelnuts decreased. The hazelnuts roasted in conventional oven and at the optimum processing conditions of microwave-infrared combination oven were comparable in terms of their free fatty acid contents.

In microwave-convective heating combination oven roasting, air temperature and roasting time were the primary factors affecting L* value, a* value, fracture force and roasting time, significantly. As air temperature and roasting time increased, it was clearly observed that a* value increased but L* value, fracture force and moisture content of hazelnuts decreased. The microwave power was found to be insignificant on affecting all of the quality parameters.

Hazelnuts roasted in microwave assisted ovens at the optimum condition had comparable quality in terms of L* value, a* value, fracture force and moisture content with conventionally roasted hazelnuts. In addition, conventional roasting time of hazelnuts was significantly reduced in microwave-infrared combination oven. Therefore, microwave-infrared combination oven can be recommended strongly for roasting of hazelnuts. Since there is no difference between the roasting times in microwave convective heating combination oven and conventional oven, microwave convective heating combination oven is not recommended as an economical substitute for conventional roasting.

Although, the quality parameters of the roasted hazelnuts were comparable with conventionally roasted ones, sensory analysis is recommended in order to make a comparison with respect to taste. The possibility of using microwave-infrared combination oven for roasting of other products in order to improve product quality and to save time can also be studied in future.

REFERENCES

Abdul-Kadir, Bargman T, Rupnow J. (1990). Effect of infrared heat processing on rehydration rate and cooking of Phaseolus vulgaris (var. Pinto). J Food Sci 55, 5, pp 1472–1473.

Açkurt, F., Özdemir, M., Löker, M., Biringen, G., (1999). Effect of geographical origin and variety on the vitamin and mineral composition of Turkish hazelnut varieties, Food Chemistry, 65, 3, pp 313-36.

Afzal T.M., Abe T. (1998). Diffusion in potato during far infrared radiation drying. J Food Eng 37, 4,pp 353–365.

Alasalvar, C., Shahidi, F., Liyanapathirana, C. M., Ohshima, T. (2003) Turkish Tombul hazelnut (Corylus aVellana L.) 1. Compositional characteristics. J. Agric. Food Chem. 51, 3790-3796.

Alphan, E., Pala, M., Açkurt, F., and Yilmaz, T. (1996). Nutritional composition of hazelnuts and its effects on glucose and lipid metabolism. Acta Horticulturae, 445, pp 305-310.

Alton, W. J., (1998). Microwave pasteurization of liquids. Society of Manufacturing Engineers. Paper No. EM 98-211.

Altundağ, N., (1989). Gıdalarda küfler ve mikotoksinler projesinde TUBITAK-Fiskobirlik işbirliği çerçevesinde Fiskobirlik'te yapılan çalışmalar, Gıdalarda Küfler ve Mikotoksinler Sempozyumu Tebliğleri. TUBITAK-MAM ve ISO.

Amaral, J. S., Casal, S., Alves, M. R., Seabra, R. M., Oliveira, B. P. P. (2006) Tocopherol and tocotrienol content of hazelnut cultivars grown in Portugal. J. Agric. Food Chem. 54, pp 1329-1336.

Ames, J. (1988). The Maillard browning reaction an update. Chemistry and Industry, 5, pp 558-561.

Anderson, J. W., Bridges, S. R. (1988) Dietary fiber of selected foods. Am. J. Clin. Nutr., 47, pp 440-447.

Anjum, F., Anwar. F., Jamil. A., Iqbal, M. (2006). Microwave roasting effects on the physico-chemical composition and oxidative stability of sunflower seed oil. Journal of the American Oil Chemists' Society , 83, pp 777–784.

Anonymous, (1995), Fındık Ekonomik Raporu, Fiskobirlik, Giresun, Türkiye

AOAC. (1984). Official methods of analysis (14th ed.). Association of Official Analytical Chemists, Washington, DC.

Ayappa, K. G., Davis, H. T., Crapiste, G., Davis, E. A., and Gordon, J., (1991). Analysis of microwave heating of materials with temperature dependent properties. American Institute of Chemical Engineers Journal, 37, 313-322.

Baker, G., Sims, C.A., Gorbet, S.F., O'keefe, C.A. and Talcott, S.T. (2003). Determination of pyrazine and flavor variations in peanut genotypes during roasting. J. Food Sci. 68, 1, pp 394-400.

Barac, M.,, Stanojevic, S., (2005),The effect of microwave roasting on soybean protein composition and components with trypsin inhibitor activity, Acta Alimentaria, 34, 1, pp 23-31.

Behera, S., Nagarajan, S., and Rao, J. M. (2004). Microwave heating and conventional roasting of cumin seeds (Cuminum cyminum L.) and effect on chemical composition of volatiles. Food Chemistry, 87, pp 25–29.

Brown, L., Rosner, B., Willett, W. W., Sacks, F. M. (1999). Cholesterol lowering effects of dietary fiber, a meta-analysis. Am. J. Clin. Nutr. 69, pp 30-42.

Buckholz, L. L., Daun, H., Stier, E. (1980). Influence of roasting time on sensory attributes of fresh roasted peanuts. Journal of Food Science, 45, pp 547-554.

Buffler, C., (1993). Microwave cooking and processing: Engineering fundamentals for the food scientist. New York: Avi Book. 6, 7, pp 150-151.

Chatterjee, A, T. Basak and K.G. Ayappa (1998), Analysis of microwave sintering of ceramics. AIChe Journal 44, 10, pp. 2302–2311

Chiou, R.Y., Chang, Y.S., Tsai, T. et al. (1991). Variation of flavor related characteristics of peanuts during roasting as affected by initial moisture contents. Journal of Agricultural Food Chemistry, 39, pp 1155-1158.

Clydesdale, F.M., (1976). lnsuumental techniques for color measurement of foods. Food Technology, pp 52-59.

Dagerskog M. (1979). Infrared radiation for food processing II. Calculation of heat penetration during infrared frying of meat products. Lebens Wissen Technol 12,5 , pp 252–7.

Datta, A.K. (1990). Heat and mass transfer in the microwave processing of food. Chemical Engineering Progress, 86, pp 47-53.

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

Decareau, R.V., (1992). Microwave foods: New product development. Connecticut: Food Nutrition Press Inc. Pp 117.

Decareau, R.V., and Peterson, R., (1986). Microwave processing and engineering. Chichester, Ellis Horwood. pp. 18-21

Demir, A. D., and Cronin K. (2005). Modeling the kinetics of textural changes in hazelnuts during roasting, Simulation Modelling Practice and Theory, 13, pp 97–107.

Demir, A. D., and Cronin, K. (2004). The thermal kinetics of texture change and the analysis of texture variability for raw and roasted hazelnuts. International Journal of Food Science and Technology, 39, pp 371–383.

Demirekler, P., Sumnu, G., and Sahin, S. (2004). Optimization of bread baking in a halogen lamp–microwave combination oven by response surface methodology. European Food Research Technology, 219, pp 341–347.

Dostie, M., Seguin, J.N., Maure, D., Tonthat, Q.A., Chatingy, R.. (1989). Preliminary measurements on the drying of thick porous materials by combinations of intermittent infrared and continuous convection heating. Mujumdar AS, Roques MA, editors. Drying'89. New York, Hemisphere Press.

Driscoll, R. H., and Madamba, P. S. (1994). Modeling the browning kinetics of garlic. Food Australia, 46, pp 66-71.

Fakhouri, M.O and Ramaswamy, H.S., (1993). Temperature uniformity of microwave heated foods as influenced by product type and composition. Food research international, 26, pp 89-95.

Fasina O.O., Tyler R.T., Pickard M. (1996). Effect of infrared heat treatment on the chemical composition and functionality of cereal grains and comparison of hulless and pearled barley. Progress Report, Dept. of Applied Microbiology and Food Science, Univ. of Saskatchewan, Saskatoon.

Fenton G.A., Kennedy M.J. (1998). Rapid dry weight determination of kiwifruit pomace and apple pomace using an infrared drying technique. New Zealand J Crop Horti Sci 26,
pp 35–38.

Francis, F.J., (1983). Colorimetry of foods. Properties of foods. hl. Peleg and E.B. Bagley (Ed.), . Wesport, AVI.09.

Giese, J., (1992). Advances in microwave food processing. Food Technology, 118-123.
Lorenz K., Charman E., Dilsaver W., 1973. Baking with microwave energy. Food Technology, 23-36.

Giovanni, (1983). Response surface methodology and product optimization. Food FoodTechnology, pp 41-83.

Gomez, J.M. and De la Torre, M.C. (1989). Influencia de la lecnologia en el valor nutritivo de los alimentos. II Lipidos. Alimentaria, 205, pp 11-18.

Hazelnut Promotion Group (http://www.ftg.org.tr/eng_main.htm)

Holland, B., Welch, A. A., Unwin, I. D., Buss, D. H., Paul, A. A., Southgate, D. A. T. (1995) McCance and Widdowson's The Composition of Foods, 5th ed., The Royal Society of Chemistry and Ministry of Agriculture, Fisheries and Food, Cambridge, U.K.

Hunter, R.S., (1976). Objective methods for appearance evaluation. Objective Methods for Food Evaluation. National Academy of Sciences. Washington D.C.. pp. 215-229

Jinap, S., Wan-Rosli, W. I., Russly, A. R., and Nordin, L. M. (1998). Effect of roasting time and temperature on volatile component profile during nib roasting of cocoa beans (Theobroma cacao). Journal of the Science of Food and Agriculture, 77, pp 441-448.

Johnson, I. T., Southgate, D. A. T. (1994) Dietary Fibre and Related Substances, Chapman and Hall, London, U.K.

Kahyaoglu, T., and Kaya, S. (2006). Determination of optimum processing conditions for hot-air roasting of hulled sesame seeds using response surface methodology. Journal of Science and Food Agriculture, 86, pp 1452–1459.

Karel, M., (1984). Environmenlal effects on chemical changes in foods. Chemical Changes in Food during Processing. T. Richardson and J.W. Finley (Ed.). Avi Publishing Company Inc., Westport, pp. 483-501.

Karel, M., (1985). Control of lipid oxidation in dried foods. Concentration and Drying of Foods. D. MacCarthy (ed.), Elsevier Applied Science Publishers, New York, pp. 37-51.

Keskin, H. (1981). Gıda Kimyası, Fatih Matbaası, Istanbul, Turkey, pp 8-20.

Keskin, S. O., (2003). Effects of different ovens and enzymes on quality parameters of bread, MS Thesis, Middle East Technical University, Ankara.

Keskin, S. O., Sumnu, G., and Sahin, S. (2004). Bread baking in halogen lamp–microwave combination oven. Food Research International, 37, pp 489–495.

Khan M.A., Vandermey P.A. (1985). Quality assessment of ground beef patties after infrared heat processing in a conveyorized tube broiler for foodservice use. J Food Sci 50, pp 707–709.

Khuri, A. I. and Cornell, J. A. (1987). Response Surfaces: Designs and Analyses. Marcel Dekker Inc. New York.

Köksal, A.I., Okay, Y., (1996). Effects of different pellicle removal on the fruit quality of some important hazelnut cultivars, Acta Horticulturae, 445, pp 327-333.

Kritchevsky, D. (1988) Dietary fiber. Annu. ReV. Nutr., 8, pp 301- 328.

Labuza, T.P. and Baisier, W.M., (1992). The kinetics of nonenzymatic browning. Physical Chemistry of foods. H. Schwartzberg and R.W. Hartel (Ed.), Dekker. NewYork, pp. 595-649.

Labuza. T.P., (1980). The effect of water activity on reaction kinetics of food deterioration. Journal of Food Technolqy. 36, pp 41-59.

Lee SC, Jeong SM, Kim SY, Park HR, Nam KC, Ahn DU. (2006). Effect of far-infrared radiation and heat treatment on the antioxidant activity of water extracts from peanut hulls. Food Chemistry, 94, pp 489–493.

Lopez, A., Pique, M.T., Boatella, J., Romero, A., Garcia, J., (1997). Influence of drying conditions on the hazelnut quality: III. Browning , Drying Technology, 15, 3and4, pp. 989-1002.

Lorenz, K., Charman, E. and Dilsaver, W. (1973). Baking with microwave energy. Food Technology, 27, pp 28-36.

Mahajan G. N., Pai J. S., (1988), Defatting of whole peanut kernels after infrared heating Food chemistry, 27, 3, pp. 237-240

Martins, S. I.F.S., Jongen, W. M. F., and Boekel, M. A. J. S. (2001). A review of Maillard reaction in food and implications to kinetic modelling. Trends in Food Science and Technology, 11, pp 364–373

Masamura A, Sado H, Nabetani H, Nakajima M. (1988). Drying of potato by far-infrared radiation. Nippon Shokuhin Kogyo Gakkaishi 35, 5, pp 309–314.

Mason, M.E., Johnson, B., Hamming, M. (1966). Flavor components of roasted peanuts. Some low molecular weight pyrazines and a pyrrole. J Agr Food Chem, 14, 5, pp 454-60.

Mason, M.E., Newell, J.A., Johnson, B.R., Koehler, P.E., (1969). Nonvolatile flavor components of peanuts, Journal of Agricultural and Food Chemistry, 14, 454

Mayer, K., (1985). Infra-red roasting of nuts, parlicularly hazelnuts. Confecrionery production, 5 l, 6, pp 313.

McKellar, C. R., Lu, X.(2004). Modeling Microbial Responses in Food, CRC Press, Canada. pp 4

Megahad, M.G., (2001). Microwave Roasting of Peanuts, Effects on Oil Characteristics and Composition. Nahrung, 45, pp 255–257

Mermelstein, N. H., (1997). How food technology covered microwaves over the years. Food Technology, 51(5), 82-84.

Metaxas, A.C., and Meredith, R.J., (1983). Industrial microwave heating. London, Peter Peregrimus. pp 6,80.

Momchilova, S., Damyanova, B. N.,(2007), Quantitative TLC and Gas Chromatography Determination of the Lipid Composition of Raw and Microwaved

Roasted Walnuts, Hazelnuts, and Almonds, Journal of Liquid Chromatography and Related Technologies, 30, pp 2267–2285.

Mongpreneet S, Abe T, Tsurusaki T. (2002). Accelerated drying of welsh onion by far infrared radiation under vacuum conditions. J Food Eng, 55, pp 147–56.

Montavon, P., Mauron, A. F., and Duruz, E. (2003). Changes in Green Coffee Protein Profiles during roasting. Journal of Agriculture and Food Chemistry, 51, pp 2335-2343.

Moss, J. R., and Otten, L. (1989). A relationship between color development and moisture content during roasting of peanut. Canadian Institute of Food Science and Technology Journal, 22, pp. 34-39.

Mudgett, R.E. (1982). Electrical properties of foods in microwave processing. Food Technology, 36: 109-115.

Murkovic M., Piironen V., Lampi A. M, Kraushofer T., and Sontag G. (2004). Changes in chemical composition of pumpkin seeds during the roasting process for production of pumpkin seed oil (Part 1, non-volatile compounds. Food Chemistry, 84, pp 359–365

Myers, R. H., and Montgomery, D. C. (2002) Response surface methodology (RSM), process and product optimization using designed experiments. Wiley-Interscience Publication, USA, pp 1-3.

Navari, P., Andrieu, J., Gevaudan, A. (1992). Studies on infrared and convective drying of nonhygroscopic solids. Mujumdar AS, editor. Drying 92. Amsterdam, Elsevier Science. Pp 685–694.

Nebesny E., and Budryn, G. (2003). Antioxidative activity of green and roasted coffee beans as influenced by convection and microwave roasting methods and content of certain compounds. European Food Research and Technology, 217, pp 157–163

Nebesny, E., and Budryn, G., (2006), Evaluation of sensory attributes of coffee brews from robusta coffee roasted under different conditions, European Food Research and Technology, 224, 2, pp 159-165.

Newell, J.A., Mason, M.E., Matlock, R.S., (1967). Precursors of typical and atypical roasted peanut flavor, Journal of Agricultural and Food Chemistry, 15, pp 767-772

Nicoli, M. C., Elizalde, B. E., Pitotti, A., and Lerici, C. R. (1991). Effect of sugars and maillard reaction products on polyphenol oxidase and peroxidase activity in food. Journal of Food Biochemistry, 15, pp 169-184.

Nowak D., Levicki P.P. (2004). Infrared drying of apple slices. Innov Food Sci Emerg Technol 5, pp 353–60.

O'Brien K.T. and A.M. Mekkaoui (1993), Numerical simulation of the thermal fields occurring in the treatment of malignant tumors by local hyperthermia. Journal of Biomechanical Engineering, 115, pp. 247–253.

O'Brien, J., and Morrissey, P. A. (1989). Nutritional and toxicological aspects of the Maillard browning reaction in foods. Critical Reviews in Food Science and Nutrition, 28, pp 211-248.

Ohlsson T., Bengtsson N., (2002). Minimal processing of foods with thermal methods. In: Minimal processing technologies in the food industry (edited by Ohlsson T., Bengtsson N.). Woodhead Publishing Limited, Cambridge, England. Pp. 13-14, 23.

Oupadissakoon, C., Young, C. T. and Mozingo, R. W. (1980). Evaluation of free amino acid and free sugar contents in five lines of Virginia-type peanuts in four locations. Peanut Science, 7 , pp. 55–60.

Ozdemir, M., (2001) Mathematical analysis of color changes and chemical parameters of roasted hazelnuts. PhD Thesis. Istanbul Technical University.

Ozdemir, M., and Devres, O. (2000a). Analysis of color development during roasting of hazelnuts using response surface methodology. Journal of Food Engineering, 45, pp 17-24.

Ozdemir, M., and Devres, O. Y. (1999). The thin layer drying characteristics of hazelnuts during roasting. Journal of Food Engineering, 42, pp 225 –233.

Ozdemir, M., Açkurt, F., Kaplan, M., Yıldız, M., Löker, M., Gürcan, T., Biringen, G., G., Okay, A., and Seyhan, F. G. (2001). Evaluation of new Turkish hybrid hazelnut (Corylus avellana L.) varieties: fatty acid composition, a-tocopherol content, mineral composition and stability. Food Chemistry, 73, 411–415.

Ozdemir, M.,& Devres, O. (2000b). Kinetics of color changes of hazelnuts during roasting. Journal of Food Engineering, 44, pp 31-38

Parcerisa, J., Boatella, J., Codony, R., Farran, A., Garcia, J., Lopez A,, Rafecas, M., Romero, A,, (1993). Influence of variety and geographical origin on the lipid fraction of hazelnuts (Corylus avellana L.) from Spain, I. Falty acid composition. Food Chemisrry, 48, pp 411-414.

Pattee, H.E., Pearson, J.L., Young, C.T. et al. (1982). Changes in roasted peanut ¯avor and other quality factors with seed size and storage time. Journal of Food Science, 47, pp. 455-460

Paulsen, K.D, D.R. Lynch and J.W. Strohbehn (1998). Three-dimensional finite, boundary, and hybrid element solutions of the Maxwell equations for lossy dieletric media. IEEE Transactions on Microwave Theory and Techniques 364, pp. 682–693.

Perren, R., & Escher, F. (1996b). Roasting technology of hazel-nuts, part III: The optimisation of the roasting procedure , Zucker und Süsswaren Wirthschaft, 49, 3, 135-138.

Perren, R., Escher, F. (1996a). Roasting technology of hazel-nuts, Part I: The influence of product temperature and roasting degree on the oxidation of roasted nuts, Zucker- und Suesswaren Wirtschaft, 49,1 , pp 12-15.

Ranjan, R., Irudayaraj, J., Jun, S.. (2002). Simulation of three-dimensional infrared drying using a set of three-coupled equations by the control volume method. Trans ASAE 45, 5 ,pp 1661– 1668.

Reyes, F.G.R., Poocharoen, B., Wrolstad, R.E., (1982). Maillard browning reaction of sugar–glycine model systems: changes in sugar concentration, color and appearance. J.
Food Sci. 47, 1376–1377.

Richardson D.G., (1996) The health benefits of eating hazelnuts, implications for blood lipid profiles, coronary heart disease, and cancer risks. ISHS Acta Horticulturae 445, IV International Symposium on Hazelnut.

Richardson, T., (1984). Controlling acyl transfer reactions of hydrolases to alter food constituents. Chemical Changes in Food during Processing. T. Richardson and J.W. Finley (ed.). Avi Publishing Company Inc., Westport, pp. 219-254.

Sahin, S., and Sumnu G.S., (2006). Physical properties of foods. New York. Springer

Sakai N, Hanzawa T., (1994). Applications and advances in far-infrared heating in Japan. Trends Food Sci Technol 5, pp 357–362.

Sakiyan. O., Sumnu, G., Sahin, S. and Meda, V. (2007). Investigation of dielectric properties of different cake formulations during microwave and infrared–microwave combination baking, Journal of Food Science 72 (4) (2007), pp. E205–E213.

Saklar, S., Katnas, S., and Ungan, S. (2001). Determination of optimum hazelnut roasting conditions. International Journal of Food Science and Technology, 36, pp 271-281.

Saklar, S., Ungan, S., Katnas, S.(1999) Instrumental crispness and crunchiness of roasted hazelnuts and correlations with sensory assessment. J. Food Sci. 64, pp 1015-1019.

Sawai J, Nakai T, Hashimoto A, Shimizu M. (2004). A comparison of the hydrolysis of sweet potato starch with b-amylase and infrared radiation allows prediction of reducing sugar production. Int J Food Sci Technol 39, pp 967–974.

Schenker S, Heinemann C, Huber M, Pompizzi R, Perren R, Escher F. (2002). Impact of roasting conditions on the formation of aroma compounds in coffee beans. J Food Sci 67(1), pp 60–66.

Sepulveda, D.R., BarbosaCanovas, G.V., (2003). Heat transfer in food products. Transport phenomena in food processing Food Preservation Technology Series. pp.42

Sevimli, K. M., Sumnu, G., and Sahin, S. (2005). Optimization of halogen lamp–microwave combination baking of cakes, a response surface methodology study. European Food Research and Technology, 221, pp 61–68.

Sharma G.P., Verma R.C., Pathare P.B.(2005). Thin-layer infrared radiation drying of onion slices. J Food Eng 67, pp 361–366.

Sheridan P., Shilton N. (1999). Application of far-infrared radiation to cooking of meat products. J Food Eng 41, pp 203–208.

Shuaeib, F.M., Hamouda, A.M.S., Wong, S.V., Radin Umar, R.S., Megat Ahmed, M.M.S, (2007), A new motorcycle helmet liner material, The finite element simulation and design of experiment optimization, Materials and Design, 28, pp 182–195.

Sumnu, G., Turabi, E., and Oztop M.(2005). Drying of carrots in microwave and halogen lamp–microwave combination ovens. LebensmittelWissenschaft und Technologie, 38, pp 549–553.

Şimşek, A., Aslantaş, R., (1999). Fındığın bileşimi ve insan beslenmesi açısından önemi, Gıda, 24, 3, pp 209-216

Takagi, S., H. Lenaga, C. Tsuchiya, and H. Yoshida, (1999), Microwave Roasting Effects on the Composition of Tocopherols and Acyl Lipids Within Each Structural Part and Section of a Soybean, Ibid. 79, pp 1155–1162.

Tariq, N., Jenkins, D. J. A., Vidgen, E., Fleshner, N., Kendall, C. W. C., Story, J. A., Singer, W., D'Coosta, M., Struthers, N. (2000) Effect of soluble and insoluble fiber diets on serum prostate specific antigen in men. J. Urol. 163, pp 114-118.

Thompson LU. (1994). Antioxidants and hormone-mediated health benefits of whole grains. Critical Reviews in Food Science and Nutrition. 34, pp 473-497.

Thomson, D. (1982). Response surface experimentation. Journal of Food Preservation. 6, pp 155-188.

Togrul H. (2005). Simple modeling of infrared drying of fresh apple slices. J Food Eng 71, pp 311– 323.

Troller, L. A. (1989). Water activity and food quality. In T.M. Hardman, Water and food quality. London, Elsevier

Turabi, E., Sumnu, G., and Sahin, S. (2008). Optimization of baking of rice cakes in infrared microwave combination oven by response surface methodology. Food and Bioprocess Technology, 1, pp 64–73.

Villota, R. and Hawkcs, J.G., (1992). Reaction kinetics in food systems. In Handbook of Food Engineering. D.R. Heldman and D.B. Lund (Ed.), Marcel Dekker Inc., New York, pp 39-144.

Wei, C.K., Davis, H.R., Davis, E.A. et al. (1985a). Heat and mass transfer water-laden sand stone: microwave heating. American Institute of Chemical Engineers Journal, 31: 842-848.

Wei, C.K., Davis, H.R., Davis, E.A. et al. (1985b). Heat and mass transfer water-laden sand stone: convective heating. American Institute of Chemical Engineers Journal, 31: 1338-1348.

World Hazelnut Production Statistics, Fiskobirlik Company. http://www.fiskobirlik.org.tr/duretim.html, 07/09/2008.

Yoshida H., and Takagi S., (1996), Vitamin E and Oxidative Stability of Soya Bean Oil Prepared with Beans at Various Moisture Contents Roasted in a Microwave Oven, J Sci Food Agric,72, pp 111-119

Yoshida, H., Hirakawa, Y., Tomiyama, Y., Miz, Y. (2003). Effects of microwave treatment on the oxidative stability of peanut (Arachis hypogeae) oils and the molecular species of their triacylglycerols. European Journal of Lipid Science and Technology, 105, pp 351–358

Yoshida, H., Hirakawa, Y., Abe, S., Mizushina, Y. (2002). The content of tocopherols and oxidative quality of oils prepared from sunflower (Helianthus annuus L.) seeds roasted in a microwave oven. European Journal of Lipid Science and Technology, 104, pp 116-122.

Yoshida, H., Shigezaki, J., Takagi, S., Kajimoto, G. (1995). Variations in the composition of various acyl lipids, tocopherols and lignans in sesame seed oils roasted in a microwave oven. Journal of the Science of Food Agriculture, 68, pp 407–415.

Yoshida, H., Tomiyama, Y., Hirakawa, Y., Mizushina, Y. (2006). Microwave roasting effects on the oxidative stability of oils and molecular species of triacylglycerols in the kernels of pumpkin (Cucurbita spp.) seeds. Journal of Food Composition and Analysis, 19, pp 330–339.

Yurttaş, H. C., Shafer, H. W., Warthesen, J. J., (2000). Antioxidant activity of nontocopherol hazelnut (Corylus spp.) phenolics, Journal of Food Chemistry, 65, pp 276-280.

APPENDIX A

PROPERTIES OF TOMBUL HAZELNUT

The proximate composition, caloric value, mineral and vitamin content, amino acid, free fatty acid compositions of Tombul hazelnut (Alasalvar et al, 2003).

Table A.1 Proximate Composition and Caloric Value of Tombul Hazelnut[a]

Composition	(g/100)
Protein	15.35±0.42
Fat	61.21±0.99
Carbohydrates[b]	17.30±0.48
Moisture	3.90±0.20
Ash	2.24±0.03
Energy[c]	631 kcal in 100g/2640 kJ in 100g

[a] Data are expressed as mean ± SD (n=6). [b] Carbohydrates were calculated by subtracting the total percent values of other measurements from 100. [c] Energy was calculated according to the MAFF (42).

Table A.2 . Mineral Content of Tombul Hazelnut[a]

Minerals	(mg/100g)	Minerals	(mg/100g)
aluminium	5.02±0.04	manganase	3.29±0.06
cadmium	0.01±0.00	nickel	1.25±0.03
calcium	193.4±0.60	phosphorous	355.7±4.16
chromium	0.01±0.00	potassium	761.0±2.65
cobalt	0.22±0.01	selenium	0.06±0.00
copper	1.60±0.02	silver	0.01±0.00
iron	4.97±0.07	sodium	3.13±0.45
lead	0.03±0.01	vanadium	0.08±0.00
magnesium	176.5±0.50	zinc	1.94±0.10

[a] Data are expressed as mean ±SD (n=3) on fresh weight basis.

Table A.3 Vitamin Content of Tombul Hazelnut[a] and Percentage of RDA

Vitamins	(mg/100 g)	% of RDA[c]
E[b]	24.0±0.54	240.0
thiamin	0.42±0.03	27.9
riboflavin	0.10±0.01	6.1
pyridoxine	0.63±0.04	31.3
cobalamin	nd[d]	0.0
niacin	1.94±0.15	10.2
Pantothenic acid	1.12±0.07	11.2
biotin	0.08±0.01	27.0
total folate	0.12±0.01	59.0
ascorbic acid	5.54±0.23	9.2
carotene	nd	0.0

[a] Data are expressed as mean ± SD (n=3) on fresh weight basis. [b] Vitamin E (α-tocopherol equivalents). [c] RDA for adults (25). [d] nd, not detected.

Table A.4 Dietary Fiber Content of Tombul Hazelnut[a]

Dietary fiber	(g/100)
Insoluble	10.67±0.15
Soluble	2.21±0.10
Total	12.88±0.24

[a] Data are expressed as mean ± SD (n=3) on a fresh weight basis.

Table A.5. Amino Acid Composition of Tombul Hazelnut[a]

Composition	(g/ 100 g hazelnut)
alanine	0.70±0.02
arginine	2.16±0.06
aspartic acid	1.52±0.04
cysteine	0.46±0.01
glutamic acid	3.13±0.08
hlycine	0.71±0.02
histidine[b]	0.45±0.01
hydroxyproline	0.06±0.00
isoleucine[b]	0.58±0.02
leucine[b]	1.07±0.03
lysine[b]	0.41±0.01
methionine[b]	0.23±0.01
phenylalanine[b]	0.66±0.02
proline	0.56±0.02
serine	0.65±0.02
threonine[b]	0.53±0.01
tryptophan[b]	0.04±0.00
tyrosine	0.53±0.01
valine[b]	0.71±0.02
total essential amino acids	4.68±0.13
total amino asids	15.16±0.41

[a] Data are expressed as mean ± SD (n=3) on a fresh weight basis. b Essential amino acids.

APPENDIX B

SAMPLE TEXTURE PROFILE ANALYSIS OF ROASTED HAZELNUTS

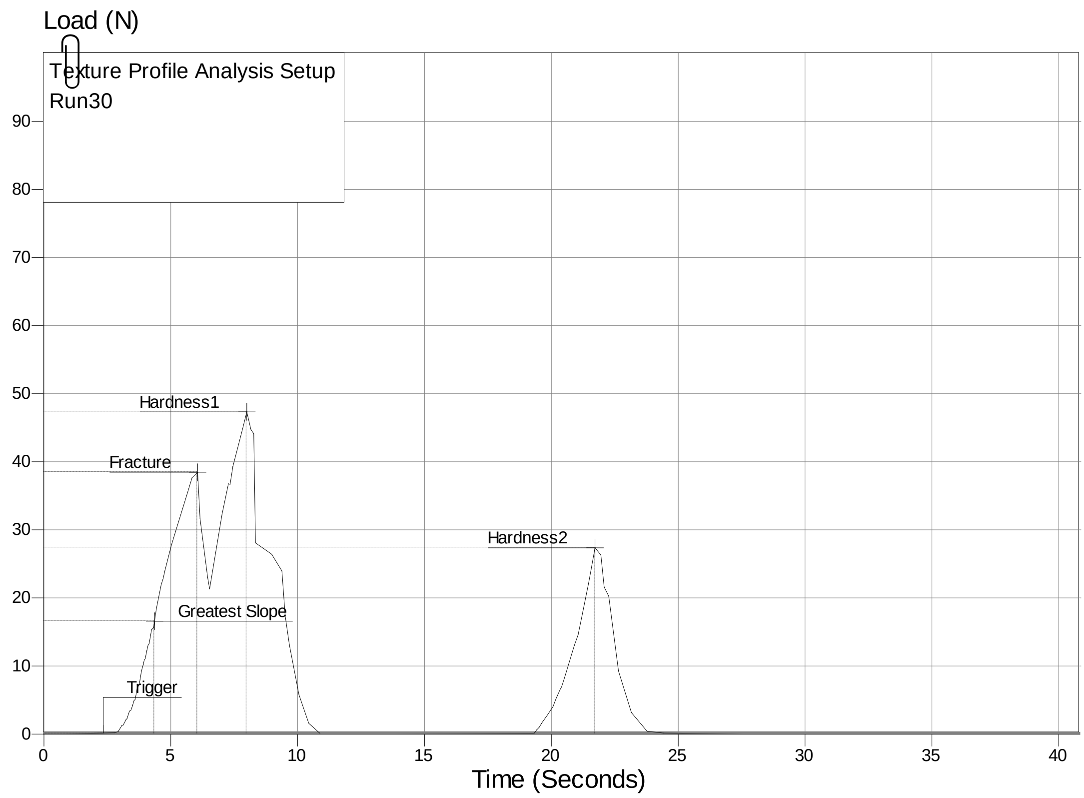


Figure B.1 Sample texture profile analysis of roasted hazelnuts

APPENDIX C

ANOVA TABLES AND REGRESSION COEFFICIENTS

Table C. 1 Regression coefficients of L* value for hazelnuts roasted in microwave-infrared combination oven.

Term	Coef	SE Coef	T	P
Constant	65,633	0,540	121,593	0,000
Block 1	1,353	0,541	2,499	0,024
Block 2	0,292	0,526	0,554	0,587
MWP	-3,276	0,423	-7,741	0,000
UHLP	-1,570	0,408	-3,848	0,001
LHLP	-1,204	0,431	-2,793	0,013
Time	-2,770	0,423	-6,546	0,000
MWP*MWP	-2,602	0,348	-7,476	0,000
time*time	-0,977	0,348	-2,808	0,013
MWP*UHLP	-2,221	0,558	-3,982	0,001
UHLP*time	-2,343	0,558	-4,201	0,001

Table C. 2 ANOVA table of L* value for hazelnuts roasted in microwave-infrared combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2,000	58,100	41,340	20,670	6,040	0,011
Regression	8,000	581,570	581,570	72,696	21,250	0,000
Linear	4,000	296,630	340,790	85,199	24,910	0,000
Square	2,000	197,550	204,110	102,056	29,830	0,000
Interaction	2,000	87,390	87,390	43,696	12,770	0,000
Residual Error	16,000	54,730	54,730	3,421		
Lack-of-Fit	13,000	37,470	37,470	2,883	0,500	0,836
Pure Error	3,000	17,260	17,260	5,754		
Total	26,000	694,410				

S = 1,84957 PRESS = 163,030
R-Sq = 92,12% R-Sq(pred) = 76,52% R-Sq(adj) = 87,19%

Table C. 3 Regression coefficients of a* value for hazelnuts roasted in microwave-infrared combination oven.

Term	Coef	SE Coef	T	P
Constant	14,234	0,355	40,155	0,000
Block 1	-0,482	0,294	-1,637	0,121
Block 2	-0,429	0,321	-1,337	0,200
MWP	2,198	0,280	7,845	0,000
UHLP	1,589	0,258	6,148	0,000
LHLP	0,177	0,115	1,539	0,050
Time	1,414	0,230	6,141	0,000
MWP*MWP	0,271	0,135	2,007	0,048
time*time	0,467	0,213	2,195	0,043

Table C. 4 ANOVA tables of a* value for hazelnuts roasted in microwave-infrared combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2	39,958	7,942	3,9709	3,56	0,053
Regression	6	157,628	155,697	25,9495	23,25	0
Linear	4	149,502	139,798	34,9494	31,31	0
Square	2	8,1259	8,1259	4,0629	3,64	0,052
Residual Error	16	17,859	17,859	1,1162		
Lack-of-Fit	13	12,275	12,275	0,9442	0,51	0,832
Pure Error	3	5,584	5,584	1,8612		
Total	24	215,445				

S = 1,05649 PRESS = 41,6306

R-Sq = 91,64% R-Sq(pred) = 80,50% R-Sq(adj) = 87,45%

Table C. 5 Regression coefficients of b* value for hazelnuts roasted in microwave-infrared combination oven.

Term	Coef	SE Coef	T	P
Constant	40,423	1,2834	31,496	0
Block 1	0,7	0,8117	0,862	0,404
Block 2	0,068	0,8117	0,084	0,934
MWP	0,115	0,6417	0,18	0,86
UHLP	0,721	0,6417	1,123	0,282
LHLP	-0,195	0,6417	-0,304	0,766
time	0,787	0,6417	1,226	0,242
MWP*MWP	0,523	0,6003	0,871	0,399
UHLP*UHLP	-0,306	0,6003	-0,509	0,619
LHLP*LHLP	0,376	0,6003	0,626	0,542
time*time	0,542	0,6003	0,902	0,383
MWP*UHLP	-0,251	0,7859	-0,32	0,754
MWP*LHLP	-0,661	0,7859	-0,841	0,416
MWP*time	-1,186	0,7859	-1,51	0,155
UHLP*LHLP	-0,551	0,7859	-0,701	0,496
UHLP*time	0	0,7859	-0,001	1
LHLP*time	0,365	0,7859	0,465	0,65

Table C. 6 ANOVA tables of b* value for hazelnuts roasted in microwave-infrared combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2	10,838	10,838	5,419	0,55	0,591
Regression	14	87,595	87,595	6,257	0,63	0,797
Linear	4	28,555	28,555	7,139	0,72	0,592
Square	4	21,53	21,53	5,383	0,54	0,706
Interaction	6	37,51	37,51	6,252	0,63	0,703
Residual Error	13	128,476	128,476	9,883		
Lack-of-Fit	10	120,217	120,217	12,022	4,37	0,126
Pure Error	3	8,259	8,259	2,753		
Total	29	226,908				

S = 3,144

R-Sq = 4,4% R-Sq(adj) = 0%

Table C. 7 Regression coefficients of fracture force for hazelnuts roasted in microwave-infrared combination oven.

Term	Coef	SE Coef	T	P
Constant	42,159	1,773	23,777	0,000
Block 1	2,669	1,427	1,870	0,080
Block 2	2,950	1,427	2,067	0,055
MWP	-6,293	1,227	-5,130	0,000
UHLP	-4,995	1,094	-4,564	0,000
LHLP	-1,572	1,094	-1,436	0,170
time	2,584	1,227	2,107	0,051
UHLP*UHLP	1,773	0,869	2,040	0,050
LHLP*LHLP	1,764	0,836	2,120	0,049
MWP*UHLP	-3,076	1,340	-2,295	0,036
UHLP*LHLP	3,102	1,340	2,314	0,034
LHLP*time	-3,746	1,340	-2,795	0,013

Table C. 8 ANOVA table of fracture force for hazelnuts roasted in microwave-infrared combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2,000	564,990	379,240	189,620	6,600	0,008
Regression	9,000	2416,082	2339,980	260,000	9,050	0,000
Linear	4,000	1675,210	1516,210	379,050	13,190	0,000
Square	2,000	210,952	210,952	105,476	3,670	0,048
Interaction	3,000	529,920	529,920	176,640	6,150	0,006
Residual Error	16,000	459,900	459,900	28,740		
Lack-of-Fit	13,000	385,030	385,030	29,620	1,190	0,505
Pure Error	3,000	74,880	74,880	24,960		
Total	27,000	3440,972				

S = 5,36135   PRESS = 1237,80
R-Sq = 86,33% R-Sq(pred) = 63,21% R-Sq(adj) = 76,94%

Table C. 9 Regression coefficients of moisture content for hazelnuts roasted in microwave-infrared combination oven.

Term	Coef	SE Coef	T	P
Constant	1,446	0,055	26,172	0,000
Block 1	0,326	0,061	5,372	0,000
Block 2	-0,184	0,072	-2,551	0,024
MWP	-0,464	0,045	-10,354	0,000
UHLP	-0,301	0,045	-6,715	0,000
LHLP	-0,200	0,045	-4,463	0,001
time	-0,419	0,045	-9,354	0,000
LHLP*LHLP	-0,151	0,040	-3,785	0,002
MWP*UHLP	0,183	0,068	2,686	0,019
MWP*LHLP	-0,243	0,068	-3,568	0,003
MWP*time	0,152	0,068	2,236	0,044
UHLP*LHLP	-0,332	0,068	-4,886	0,000
LHLP*time	-0,330	0,068	-4,859	0,000

Table C. 10 ANOVA table of moisture content for hazelnuts roasted in microwave-infrared combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2,000	1,054	1,263	0,631	14,750	0,000
Regression	10,000	13,752	13,752	1,375	32,130	0,000
Linear	4,000	8,678	8,678	2,170	50,680	0,000
Square	1,000	0,538	0,613	0,613	14,330	0,002
Interaction	5,000	4,536	4,536	0,907	21,190	0,000
Residual Error	13,000	0,557	0,556	0,043		
Lack-of-Fit	12,000	0,527	0,527	0,044	1,490	0,571
Pure Error	1,000	0,029	0,029	0,029		
Total	25,000	15,363				

S = 0,206896 PRESS = 2,84278
R-Sq = 96,38% R-Sq(pred) = 81,50% R-Sq(adj) = 93,03%

Table C. 11 Regression coefficients of L* value for hazelnuts roasted in microwave-convective heating combination oven.

Term	Coef	SE Coef	T	P
Constant	56,827	0,506	112,224	0,000
MWP	-0,971	0,693	-1,400	0,195
Temp	-3,871	0,693	-5,583	0,000
Time	-2,442	0,693	-3,521	0,007
MWP*Temp	-3,158	0,981	-3,221	0,010
Temp*Time	-3,833	0,981	-3,909	0,004

Table C. 12 ANOVA tables of L* value for hazelnuts roasted in microwave-convective heating combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5,000	273,779	273,779	54,756	14,240	0,000
Linear	3,000	175,101	175,101	58,367	15,180	0,001
Interaction	2,000	98,678	98,678	49,339	12,830	0,002
Residual Error	9,000	34,615	34,615	3,846		
Lack-of-Fit	7,000	30,627	30,627	4,375	2,190	0,348
Pure Error	2,000	3,987	3,987	1,994		
Total	14,000	308,394				

S = 1,96115   PRESS = 116,402
R-Sq = 88,78% R-Sq(pred) = 62,26% R-Sq(adj) = 82,54%

Table C. 13 Regression coefficients of a* value for hazelnuts roasted in microwave-convective heating combination oven.

Term	Coef	SE Coef	T	P
Constant	13,307	0,277	48,071	0,000
Temp	2,337	0,379	6,167	0,000
Time	2,279	0,379	6,013	0,000
Temp*Time	2,142	0,536	3,995	0,002

Table C. 14 ANOVA table of a* value for hazelnuts roasted in microwave-convective heating combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3,000	103,615	103,615	34,538	30,050	0,000
Linear	2,000	85,268	85,268	42,634	37,090	0,000
Interaction	1,000	18,347	18,347	18,347	15,960	0,002
Residual Error	11,000	12,643	12,643	1,149		
Lack-of-Fit	5,000	4,401	4,401	0,880	0,640	0,679
Pure Error	6,000	8,242	8,242	1,374		
Total	14,000	116,258				

S = 1,07209   PRESS = 21,1788

R-Sq = 89,12% R-Sq(pred) = 81,78% R-Sq(adj) = 86,16%

Table C. 15 Regression coefficients of L* value for hazelnuts roasted in microwave-convective heating combination oven.

Term	Coef	SE Coef	T	P
Constant	22,155	4,105	5,397	0,001
Temp	-11,218	2,966	-3,782	0,005
Time	-9,906	3,226	-3,071	0,015
Temp*Temp	10,531	4,562	2,308	0,050
Time*Time	21,180	4,508	4,699	0,002
Temp*Time	-9,276	4,194	-2,212	0,058

Table C. 16 ANOVA table of L* value for hazelnuts roasted in microwave-convective heating combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5,000	4071,700	4071,700	814,340	11,570	0,002
Linear	2,000	1780,200	1670,300	835,130	11,870	0,004
Square	2,000	1947,300	1947,300	973,640	13,840	0,003
Interaction	1,000	344,200	344,200	344,200	4,890	0,058
Residual Error	8,000	563,000	563,000	70,370		
Lack-of-Fit	3,000	309,500	309,500	103,150	2,030	0,228
Pure Error	5,000	253,500	253,500	50,700		
Total	13,000	4634,700				

S = 8,38869   PRESS = 2143,78
R-Sq = 87,85% R-Sq(pred) = 53,74% R-Sq(adj) = 80,26%

Table C. 17 Regression coefficients of fracture force for hazelnuts roasted in microwave-convective heating combination oven.

Term	Coef	SE Coef	T	P
Constant	2,349	0,275	8,530	0,000
Temp	-1,068	0,255	-4,187	0,002
Time	-1,127	0,236	-4,784	0,001
Time*Time	0,945	0,362	2,606	0,028
Temp*Time	-0,857	0,333	-2,572	0,030

Table C. 18 ANOVA table of fracture force for hazelnuts roasted in microwave-convective heating combination oven.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4,000	25,214	25,214	6,304	14,190	0,001
Linear	2,000	19,258	17,954	8,977	20,210	0,000
Square	1,000	3,017	3,017	3,017	6,790	0,028
Interaction	1,000	2,939	2,939	2,939	6,620	0,030
Residual Error	9,000	3,998	3,998	0,444		
Lack-of-Fit	4,000	2,570	2,570	0,643	2,250	0,199
Pure Error	5,000	1,428	1,428	0,286		
Total	13,000	29,212				

S = 0,666497 PRESS = 13,4591
R-Sq = 86,31% R-Sq(pred) = 53,93% R-Sq(adj) = 80,23%

APPENDIX D

ANDERSON & DARLING TEST AND BARTLETT'S TEST

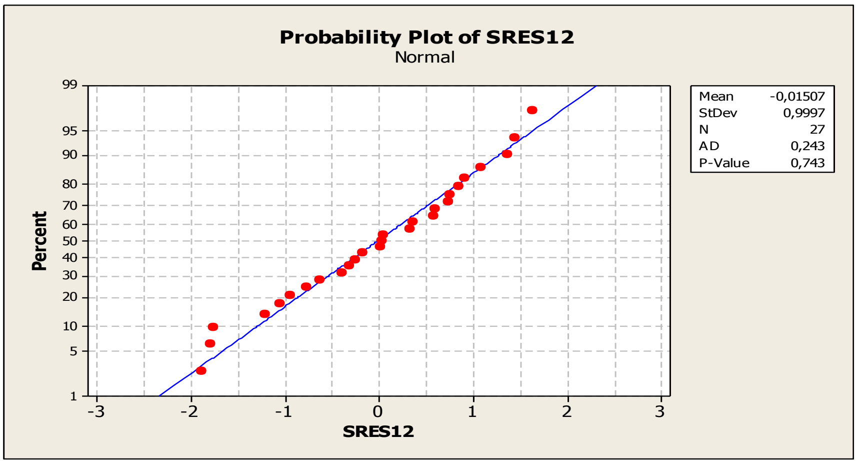


Figure D.1 Normality test (Anderson & Darling Test) plot of residuals of L* value regression model for hazelnuts roasted in microwave-infrared oven (P-value=0.743)

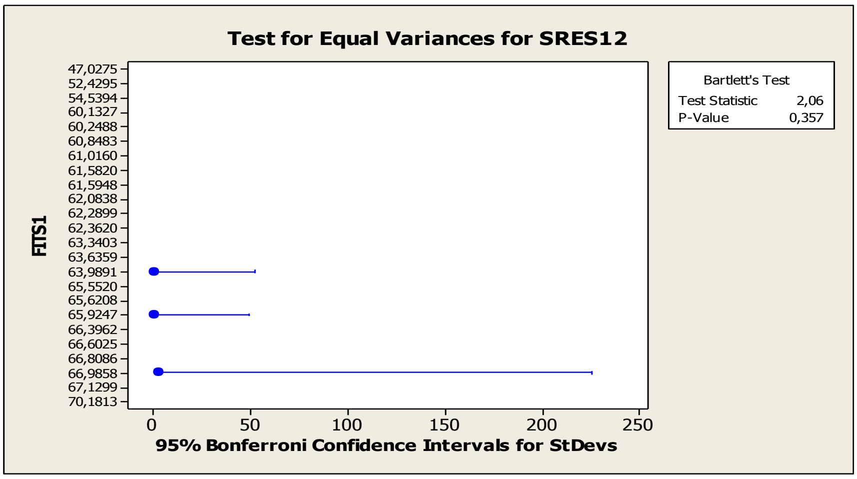


Figure D.2 Bartlett's Test plot of residuals of L* value regression model for hazelnuts roasted in microwave-infrared oven (P-value=0.357)

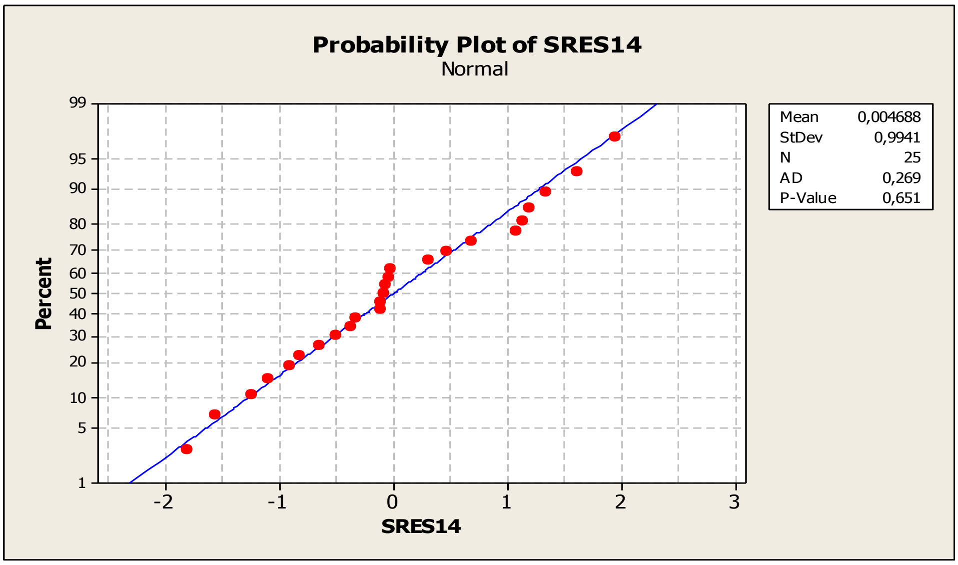


Figure D.3 Normality test (Anderson & Darling Test) plot of residuals of a* value regression model for hazelnuts roasted in microwave-infrared oven (P-value=0.651)

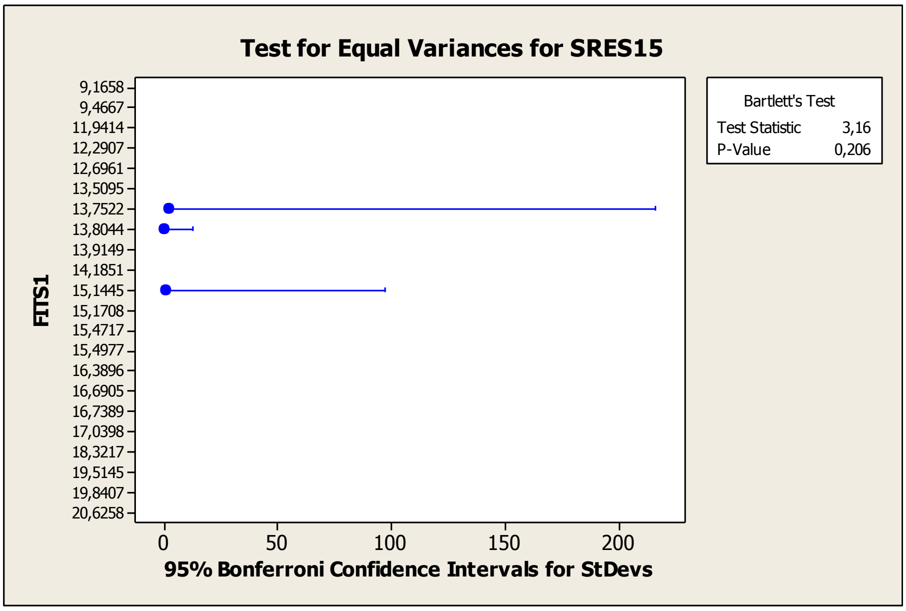


Figure D.4 Bartlett's Test plot of residuals of a* value regression model for hazelnuts roasted in microwave-infrared oven (P-value=0.206)

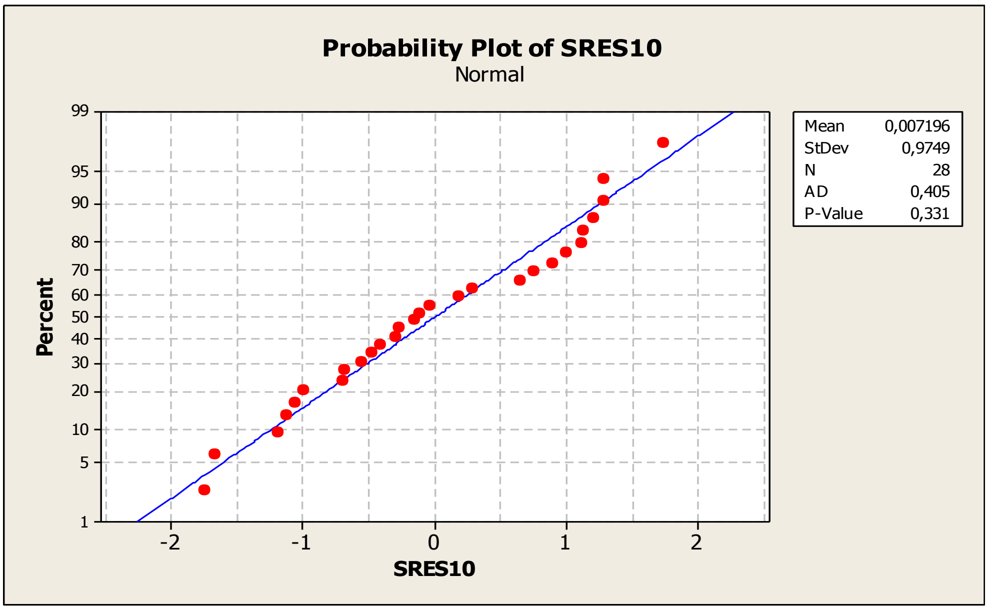


Figure D.5 Normality test (Anderson & Darling Test) plot of residuals of fracture force regression model for hazelnuts roasted in microwave-infrared oven (P-value=0.331)

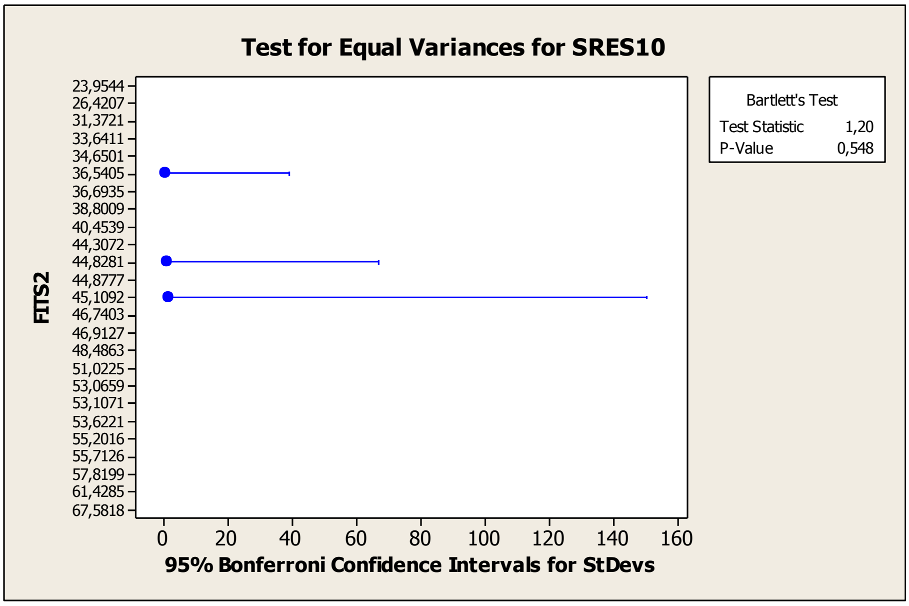


Figure D.6 Bartlett's Test plot of residuals of fracture force regression model for hazelnuts roasted in microwave-infrared oven (P-value=0.548)

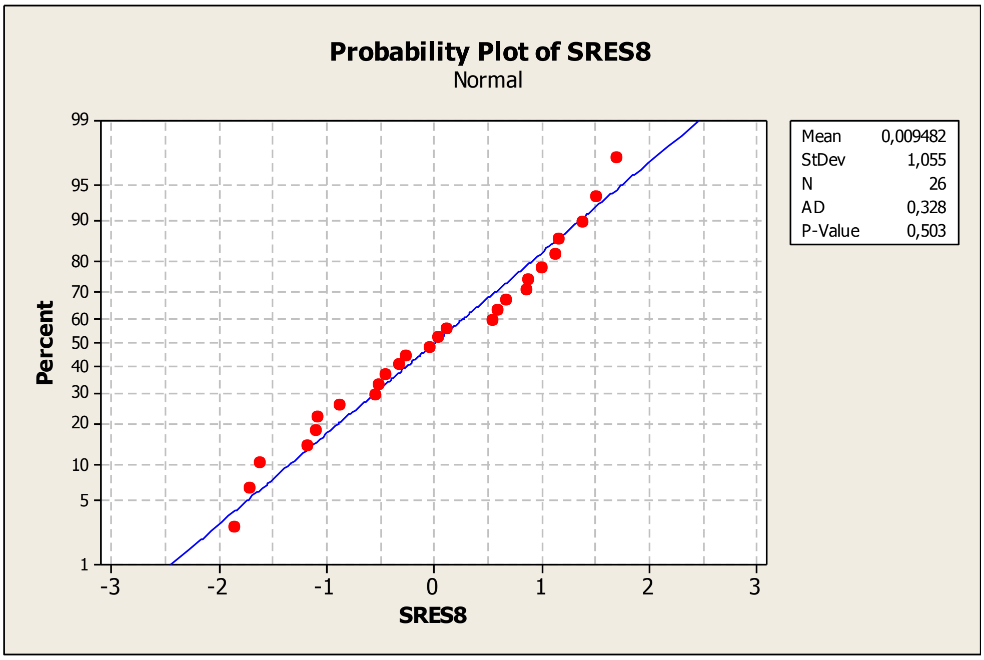


Figure D.7 Normality test (Anderson & Darling Test) plot of residuals of moisture content regression model for hazelnuts roasted in microwave-infrared oven (P-value=0.503)

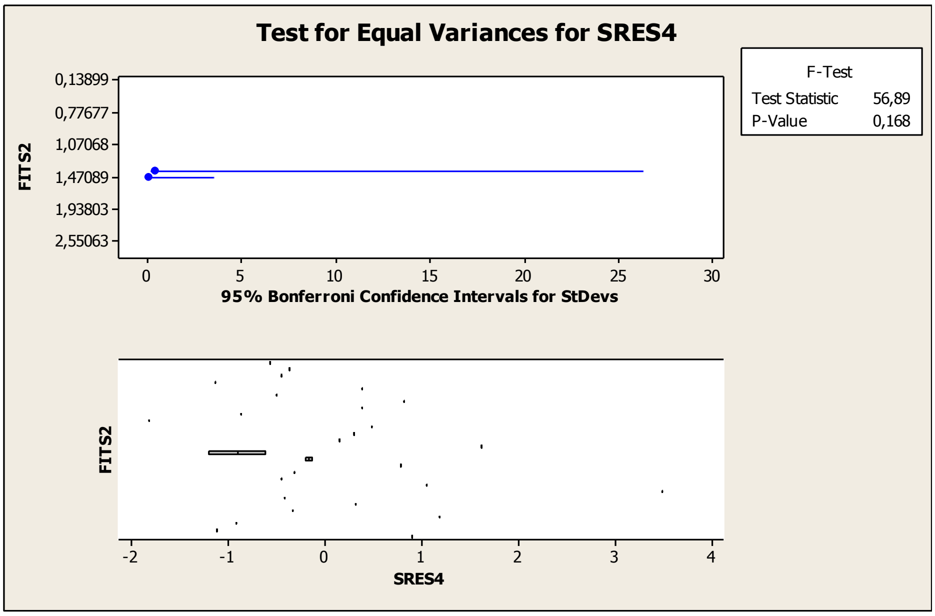


Figure D.8 Bartlett's Test plot of residuals of moisture content regression model for hazelnuts roasted in microwave-infrared oven (P-value=0.168)

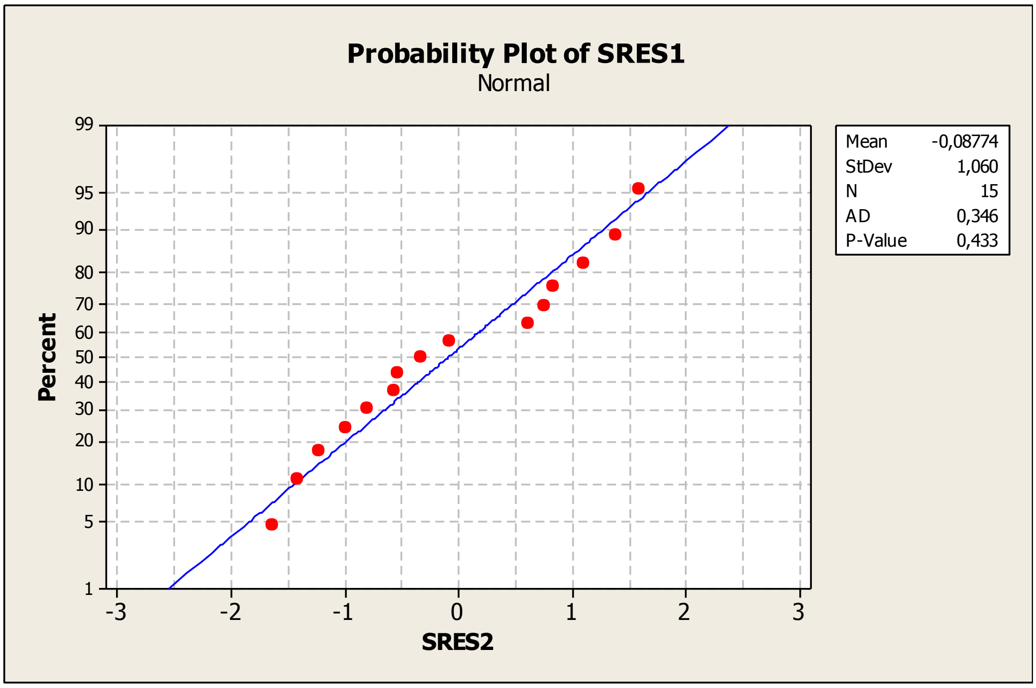


Figure D.9 Normality test (Anderson & Darling Test) plot of residuals of L* value regression model for hazelnuts roasted in microwave-convective heating oven (P-value=0.433)

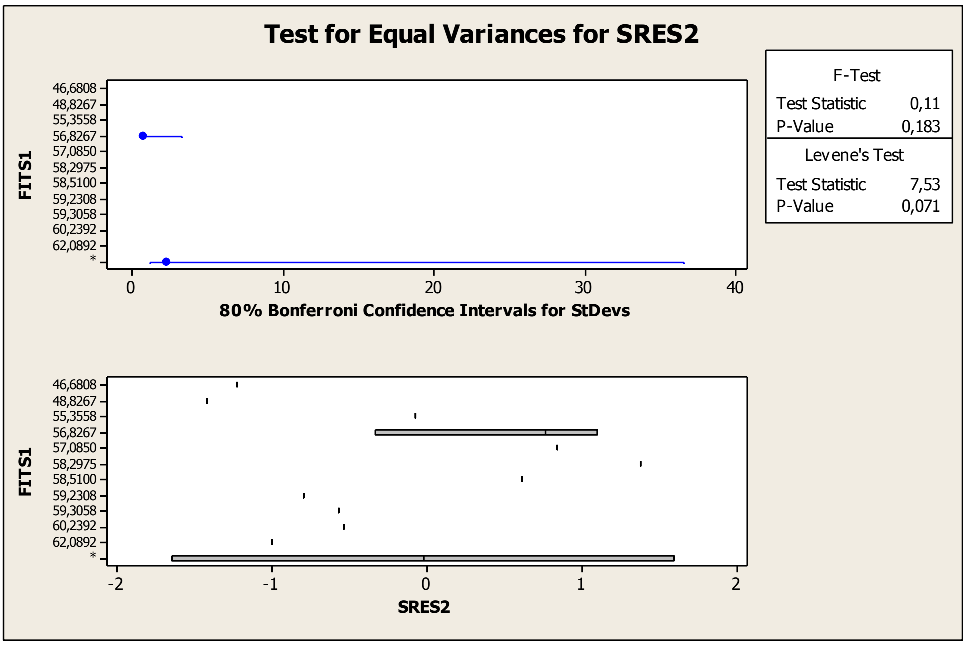


Figure D.10 Bartlett's Test plot of residuals of L* value regression model for hazelnuts roasted in microwave-convective combination oven (P-value=0.071)

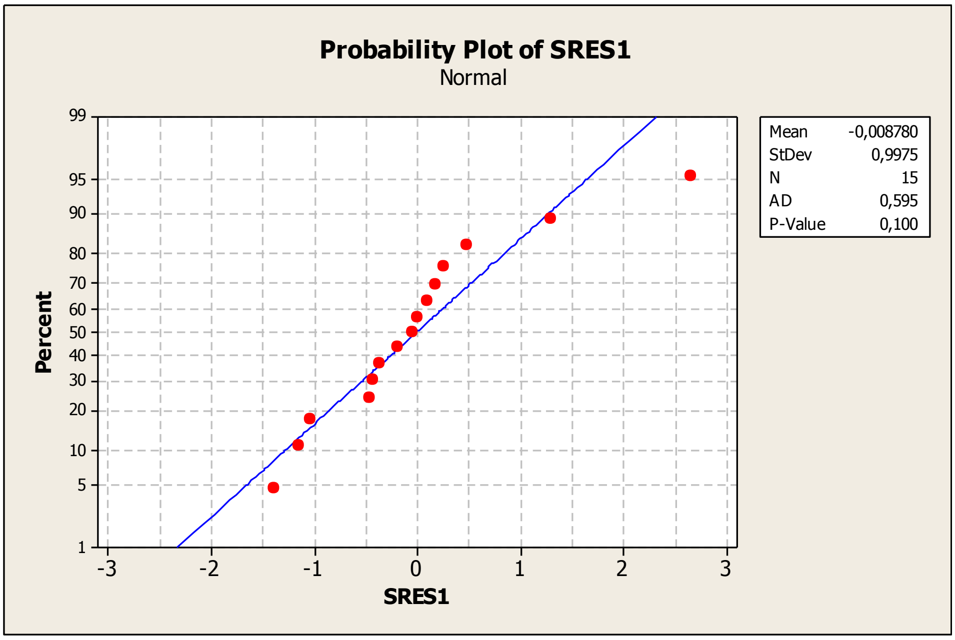


Figure D.11 Normality test (Anderson & Darling Test) plot of residuals of a* value regression model for hazelnuts roasted in microwave-convective heating oven (P-value=0.100)

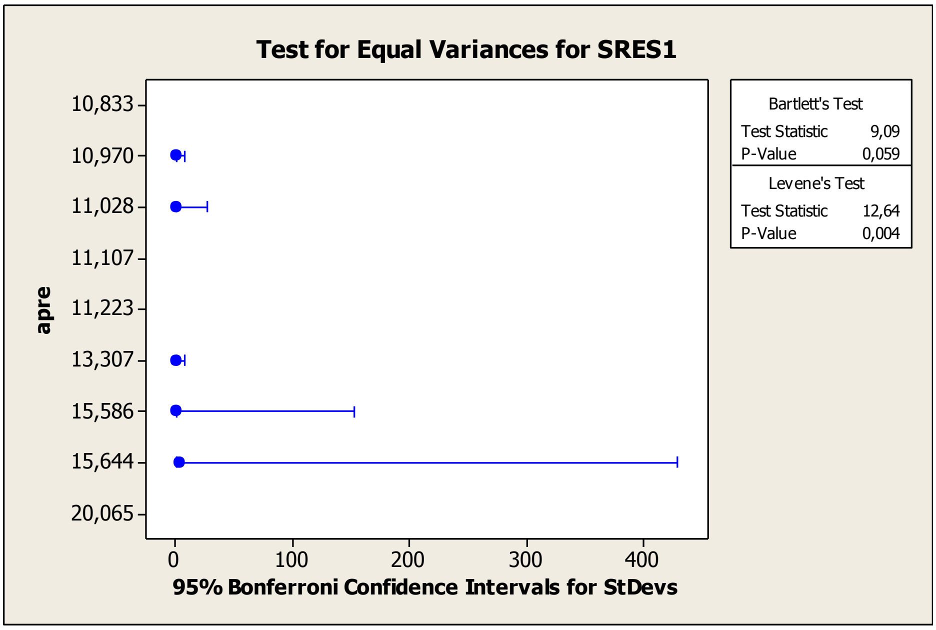


Figure D.12 Bartlett's Test plot of residuals of a* value regression model for hazelnuts roasted in microwave-convective combination oven (P-value=0.059)

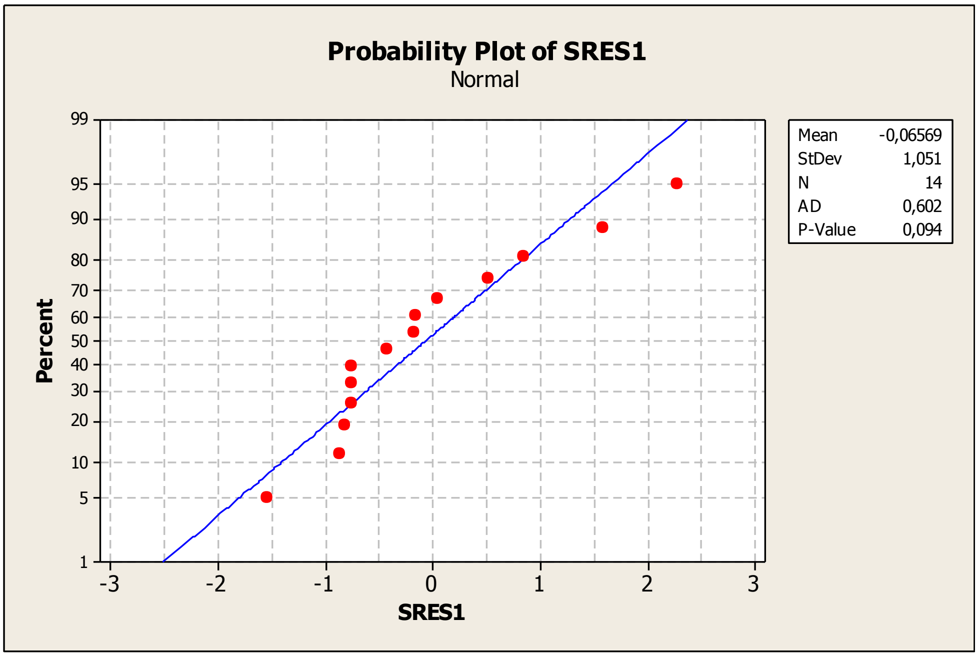


Figure D.13 Normality test (Anderson & Darling Test) plot of residuals of fracture force value regression model for hazelnuts roasted in microwave-convective heating combination oven (P-value=0.094)

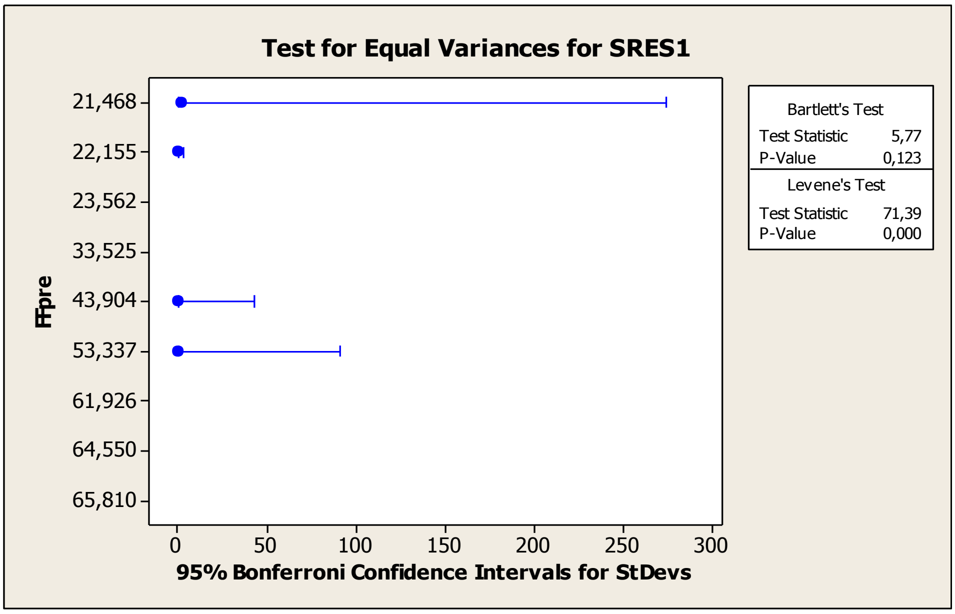


Figure D.14 Bartlett's Test plot of residuals of fracture force regression model for hazelnuts roasted in microwave-convective combination oven (P-value=0.123)

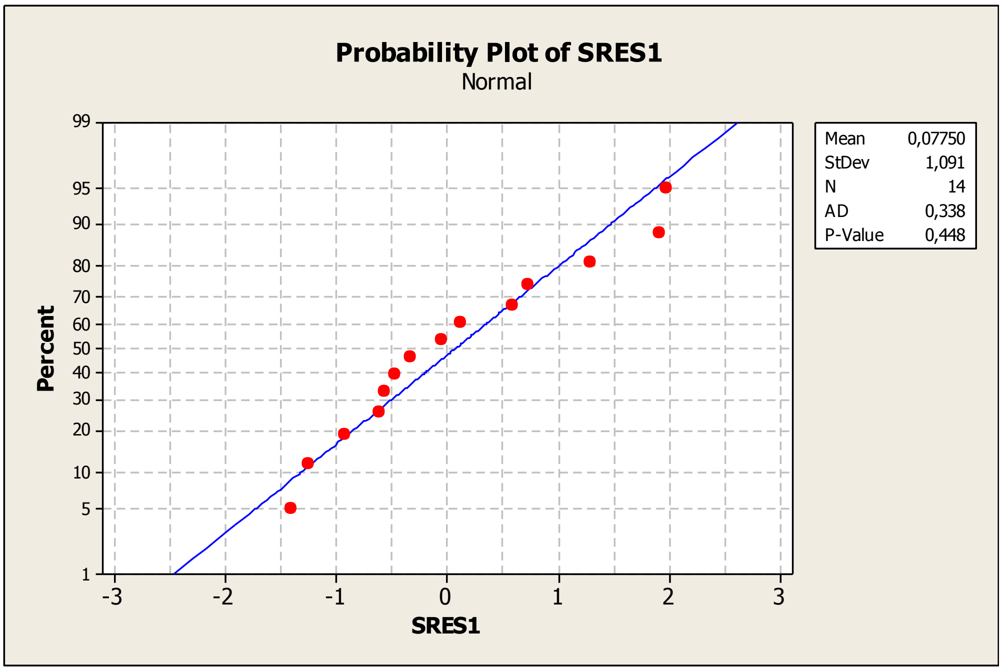


Figure D.15 Normality test (Anderson & Darling Test) plot of residuals of moisture content value regression model for hazelnuts roasted in microwave-convective heating combination oven (P-value=0.448)

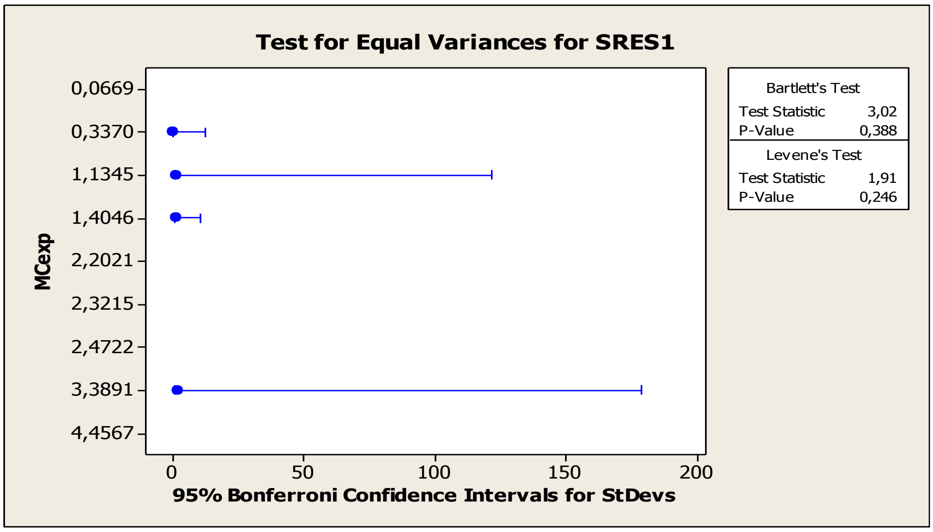


Figure D.16 Bartlett's Test plot of residuals of moisture content regression model for hazelnuts roasted in microwave-convective combination oven (P-value=0.388)

APPENDIX E

MATLAB PROGRAMS

The Matlab Program was used to find the optimum roasting condition in microwave-infrared combination oven. For this purpose, the following Matlab line was used.

```
x0=[0 0 0 0]';[x,fval,exitflag]=fmincon('f',x0,[],[],[],[],[-2 -2 -2 -2]',[2 2 2
2]','nonlincon')
```

In this line x0 determines the starting initial point of the optimization problem. Central Composite Design has 5 levels between -2 and 2, this interval was entered in the program. "fmincon" is a Matlab program that minimizes a nonlinear function of several variables with some equality or inequality, linear or nonlinear constraints. FMINCON solves problems of the form:

Min f (x)

$Ax \leq b$, $A_{eq}\, x \leq b_{eq}$

$C(x) \leq 0$, $C_{eq}(x)=0$

$lb \leq x \leq ub$

where $C(x) \leq 0$ and $C_{eq}(x) = 0$ are nonlinear constraints and *lb* and *ub* are the upper and lower bounds for the variables in the vector form. In this study, nonlinear constraints were named as "nonlincon".

The arguments of 'fmincon' that were used in this study were 'f' that represented the function minimized, x0 which was the initial point, and the symbol [ ] that denoted the empty values for A , b , A_{eq} , and b_{eq} values. The other arguments were the two 4 dimensional vectors which represented the upper and lower bonds, and 'nonlincon' was the nonlinear constraint of the presentation.

The factors 'nonlincon' and 'f' were defined by the following routines written for the problem:

1.Function 'nonlincon': This function defined the nonlinear constraint, namely a* and L* values that should be between 17-19 and 46-52, respectively.

```
function[c,a]=nonlincon(x)
qL=[-2.602 -1.1105 0 0;-1.1105 0 0 -1.1715;0 0 0 0;0 -1.1715 0 -0.977];
lL=[-3.276 -1.57 -1.204 -2.77]';
cL=65.633;
L=x'*qL*x+x'*lL+cL;
qa=[0.2713 0 0 0;0 0 0 0;0 0 0 0;0 0 0 0.4671];
la=[2.198 1.5886 0.1766 1.4136]';
ca=14.2337;
ac=x'*qa*x+x'*la+ca;
c=[L-52 -L+46 ac-19 -ac+17]';
a=[];
```

2. Function 'f': This function is the function that FMINCON minimized according to the constraints 'nonlincon' and upper and lower values of the independent variables.

```
function[y]=f(x)
lambda=1;
qmc=[0 0.18254/2 -0.24247/2 0.151965/2;0.18254/2 0 -0.332035/2 0;-0.24247/2 -
0.332035/2 -0.150939 -0.33021/2;0.151965/2 0 -0.33021/2 0];
```

```
lmc=[-0.46378 -0.300785 -0.199925 -0.418999]';
cmc=1.44565;
qFF=[1.073 -3.076/2 0 0;-3.076/2 1.773 3.102/2 0;0 3.102/2 1.764 -3.746/2;
0 0 -3.764/2 0];
lFF=[-3.276 -1.57 -1.204 -2.77]';
cFF=42.159;
y=x'*qFF*x+x'*lFF+cFF-lambda*(x'*qmc*x+x'*lmc+cmc);
```

Here ‘qL’, ‘lL’, ‘cL’, and ‘qa’, ‘la’, and ‘ca’, are used to define the second order equations of L* value and a* value, respectively in terms of a matrix, i.e. “L” stands for L* value and “ca” stands for a* value. ‘qL’ and ‘qa’ represent the matrix written for the second order terms ($X1^2$, $X2^2$, $X3^2$, $X4^2$) and the interaction terms (X_1X_2, X_1X_3, X_1X_4, X_2X_3, X_2X_4, X_3X_4). ‘lL’ and ‘la’ are the matrices defined for the first order terms (X_1, X_2, X_3, and X_4) and ‘cL’ and ‘ca’ are the constant terms in the second order polynomial fitted for the parameters of L* and a* values respectively. ‘L’ and ‘ac’ are the total equations representing the L* and a* values respectively.

‘qmc’, ‘lmc’, ‘cmc’, and ‘qFF’, ‘lFF’, ‘cFF’ are used to define the second order equations of moisture content and fracture force respectively. Here again, ‘qmc’ and ‘qFF’ represent the matrix written for the second order terms and the interaction terms. ‘lmc’ and ‘lFF’ are the matrices defined for the first order terms and ‘cmc’ and ‘cFF’ are the constant terms in the second order polynomial fitted for the parameters of firmness and specific volume respectively. ‘y’ is the total equation that is minimized in order to obtain minimum fracture force and maximum moisture content.

The Matlab Program was used to find the optimum roasting condition in microwave-convective heating combination oven. For this purpose, the following Matlab line was used.

```
x0=[0 0 0]';[x,fval,exitflag]=fmincon('f',x0,[],[],[],[-1 -1 -1]',[1 1 1]','nonlincon')
```

1. nonlinear constraint program of microwave-infrared combination oven roasting was modified accordingly.

```
function[c,a]=nonlincon(x)
qL=[0 -3.1583/2  0;-3.1583/2 0 -3.8333/2 ;0 -3.8333/2 0];
lL=[-0.9708 -3.87 -2.4417]';
cL=56.8262;
L=x'*qL*x+x'*lL+cL;
qa=[0 0 0;0 0 2.142/2 ;0 2.142/2 0];
la=[0 2.337 2.279 ]';
ca=13.307;
ac=x'*qa*x+x'*la+ca;
c=[L-52 -L+46 ac-19 -ac+17]';
a=[];
```

2. the function minimized was modified accordingly:

```
function[y]=f(x)
lambda=1;
qmc=[0 0 0;0 0 -0.8572/2;0 -0.8572/2 0.9446];
lmc=[0 -1.0676 -1.1273]';
cmc=2.3492;
qFF=[0 0 0 ;0 10.531 -9.276/2 ;0 -9.276/2 21.276];
lFF=[0 -11.218 -9.906]';
cFF=22.155;
y=x'*qFF*x+x'*lFF+cFF-lambda*(x'*qmc*x+x'*lmc+cmc);
```