OPTIMIZATION OF MICROWAVE FRYING OF POTATO SLICES

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

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ABSTRACT

OPTIMIZATION OF MICROWAVE FRYING OF POTATO SLICES

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The main objective of this study is to evaluate the effects of microwave frying process on the quality of potato slices and to optimize the process by using different statistical optimization techniques.

Use of microwave frying for food products may be considered as a new way of improving the quality of the fried foods. In the first part of the study, the effects of microwaves on quality of fried potatoes (moisture content, oil content, color and hardness) were studied and the process was optimized by using *Taguchi Technique*. Microwave power level (400W, 550W and 700W), frying time (2.0, 2.5, 3.0 minutes) and oil type (sunflower, corn and hazelnut oil) were the parameters used in the study. Moisture content of potatoes decreased whereas oil content, hardness and ΔE values of the potatoes increased with increasing frying time and microwave power level. The potatoes with the highest oil content were found to be the ones that were fried in the hazelnut oil. The optimum condition was found as frying at 550W microwave power level, for 2.5 minutes in sunflower oil. The potatoes that were fried at the optimum condition were determined to have lower oil contents compared to the ones fried conventionally.

In the second part of the study, osmotic dehydration was applied prior to microwave frying process in order to reduce oil uptake and to evaluate the effect of osmotic dehydration with microwaves on quality of fried potatoes. The process was optimized by using both Taguchi Technique and Response Surface Methodology. Microwave power level (400W, 550W and 700W), frying time (1.5, 2.0, 2.5 minutes) and osmotic dehydration time (15, 30, 45 minutes) were the parameters used in the study. Osmotic dehydration treatment was conducted in a salt solution of 20 % (w/w) at 30°C. Moisture content decreased whereas oil content, hardness and ΔE value of potatoes increased with increasing frying time and microwave power level. Dehydration of potatoes osmotically prior to frying reduced the oil content of fried potatoes. The optimum condition was found as frying at 400 W microwave power level for 1.5 min after 30 min of osmotic dehydration time according to Taguchi Technique. Microwave power level and frying time were the same as Taguchi Technique but osmotic dehydration time was 39 min for the optimum condition found using response surface methodology.

Keywords: Microwave Frying; Optimization; Osmotic Dehydration; Response Surface Methodology (RSM); Taguchi Technique.

ÖZ

PATATES DİLİMLERİNİN MİKRODALGA İLE KIZARTILMASI İŞLEMİNİN OPTİMİZASYONU

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Bu çalışmanın amacı, mikrodalga ile kızartma işleminin patates dilimlerinin kalitesi üzerindeki etkisini araştırmak ve bu işlemi farklı istatistiksel teknikler kullanarak optimize etmektir.

Mikrodalga ile kızartma işlemi, kızarmış gıda ürünlerinin kalitesini artırmak için yeni bir yol olarak önerilebilir. Bu çalışmanın ilk kısmında mikrodalganın kızartılmış patateslerin kaliteleri (nem ve yağ içeriği , renk ve sertlik) üzerindeki etkisi incelenmiştir. Bunun yanı sıra, kızartma işlemi Taguçi Tekniği kullanılarak optimize edilmiştir. Mikrodalga güç seviyesi (400 W, 550 W, 700 W), kızartma süresi (2.0,2.5,3.0 dakika) ve farklı yağ tipleri (ayçiçek, mısır ve fındık yağı) çalışmada kullanılan parametrelerdir. Mikrodalga gücü ve kızartma süresi arttıkça patateslerin nem içeriği azalmış, yağ içeriği, sertlik ve renk değişim (ΔE) değerleri ise artış göstermiştir. Yapılan optimizasyon sonucunda mikrodalganın 550 fırın gücü ile ayçiçek yağında 2.5 dakika kızartılan patateslerin en iyi kaliteye sahip oldukları görülmüştür. Optimum koşulda kızartılan patateslerin yağ içeriğinin konvansiyonel yöntemle kızartılan pataterslerinkine oranla daha az olduğu tespit edilmiştir.

Çalışmanın ikinci kısmında patateslere kızartma öncesinde, yağ emilimini azaltmak ve osmotik dehidrasyon yönteminin mikrodalga ile etkileşiminin patatesin kalite parametreleri üzerindeki (nem, yağ, renk, tekstür) etkisini görmek için osmotik dehidrasyon yöntemi uygulanmıştır. Kızartma işlemi bu defa hem Taguçi hem de Yanıt Yüzey Metodu kullanılarak optimize edilmiştir. Mikrodalga güç seviyesi (400 W, 550 W, 700 W), kızartma süresi (1.5, 2.0, 2.5 dakika) ve osmotik dehidrasyon süresi (15, 30, 45 dakika) çalışmada kullanılan parametrelerdir. Osmotik dehidrasyon uygulaması 30 ^{o}C' deki % 20'lik (ağırlıkça) tuz çözeltisinde gerçekleştirilmiştir. Nem içeriği, güç seviyesi ve kızartma süresi arttıkça bir azalış göstermiş, yağ içeriği ise artış göstermiştir. Renk analizi sonuçlarında, toplam renk değişiminin (ΔE) kızartma süresi ve mikrodalga güç seviyesi arttıkça arttığı gözlemlenmiştir. Patateslerin kızartılmadan önce osmotik dehidrasyona tabi tutulması kızartılmış patateslerin yağ içeriğini azaltmıştır. Optimum kızartma koşulu, Taguçi Tekniğine göre 30 dakika osmotik dehidrasyon süresinden sonra kızartmanın mikrodalganın 400 W fırın gücünde 1.5 dakika sürecince gerçekleştiği nokta olarak bulunmuştur. Yanıt Yüzey Metoduna göre ise mikrodalga güç seviyesi ve kızartma süresi Taguçi tekniğiyle aynı ancak osmotik dehidrasyon süresi 39 dakika olarak bulunmuştur.

Anahtar Sözcükler: Mikrodalga ile Kızartma; Optimizasyon; Osmotik Dehidrasyon; Taguçi Tekniği; Yanıt Yüzey Metodu (YYM)

Dedicated To My Father

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INTRODUCTION

1.1 Potato

The history of the potato has its roots in the windswept Andes Mountains of South America. The tough pre-Columbian farmers first discovered and cultivated the potato 7,000 years ago. They were impressed by its ruggedness, storage quality and its nutritional value. And it was even later, about 1570, that the first potato made its way across the Atlantic to make a start on the continent of Europe.

It took three decades for the potato to spread to the rest of Europe. Europe waited until the 1780's before the potato gained prominence anywhere. About 1780 the people of Ireland adopted the rugged food crop. The primary reason for its acceptance in Ireland was its ability to produce abundant, nutritious food. Unlike any other major crop, potatoes contain most of the vitamins needed for sustenance.

Soon the potato gained wide acceptance across Europe and eventually made its way back over the Atlantic to North America. As time passed, the potato became one of the major food stuffs of the world (http:// www.indepthinfo.com/potato/history.shtml.

Today, the potato is so common and is the world’s root and tuber crop grown in the greatest quantities (FAO, 1999).

Water content of potatoes is about 80-82 percent and it gives 97 kcal per 100 grams. Potatoes are good sources of carbohydrate (22.6 grams / 100 grams) and only 1.6 grams of protein for 100 grams. The fat content is less in potato. Content of minerals and water soluble B group vitamins in potatoes is small but significant. The vitamin C content of freshly dug potato is high being 30mg per 100 gram but is reduced to 8 mg after storage of 9 months. The sodium content of potato is less but it is rich in potassium content (http://www.bawarchi.com/health/potato.html).

1.2 Conventional Deep-Fat Frying

Deep-fat frying can be defined as the process of drying and cooking through contact with oil (Sahin, Sastry and Bayindirli, 1999). Deep-fat frying is widely used in preparation of foods, because the consumers prefer the taste, appearance and texture of fried food products (Lelas, Rimac-Brnčić, Rade and Šimundić, 2004). It is important that the deep-fat fried products should satisfy both health and sensory aspects of the consumer demand. High heat transfer rates are largely responsible for the development of desired sensorial properties in fried products (Hubbard and Farkas, 1999).

During frying, simultaneous heat and mass transfer occur. Upon addition of the food to the hot oil, the surface temperature of the food rises and the water at the surface immediately starts boiling. Due to the evaporation, surface drying is seen. The evaporation also leads to shrinkage and crust formation (Mellema, 2003). Heat transferred from the oil to the food causes conversion of inner moisture to steam, which creates a pressure gradient as the surface dries out. By the help of capillaries and channels in the cellular structure this pressure gradient within the product gently ‘pumps’ the water from the core of the food to the crust, which will be removed during frying. At the same time, oil adheres to product’s surface at the damaged areas and enters the voids left by the water vapor (Debnath, Bhat and Rastogi, 2003). The fact that the vapor leaves voids for the oil to enter later, is the reason why the moisture content of the food largely determines oil uptake (Gamble, Rice and Selman, 1987a; Lamberg, Hallstrom and Ollson, 1990; Mehta and Swinburn, 2001; Saguy and Pinthus, 1995; Southern, Farid, Howard and Eynes, 2000).

Deep-fat fried products contain a substantial amount of fat since foods with low fat content absorb large amounts of oil during deep-fat frying. Oil absorption of the food is affected by many factors including process conditions (temperature, time), pre-treatment of the food (such as by dehydration methods), physico-chemical characteristics of food, oil origin, chemical composition of oil and others. Longer times and lower frying temperatures usually lead to higher final oil contents in fried potato products.

1.3 Oil Types Used in Frying

The most commonly used oil for frying is the sunflower oil due to its high smoke point (227 ^{o}C). Corn oil may also be an alternative for sunflower oil. The smoke point of corn oil is close to the sunflower oil (232 ^{o}C). In terms of fatty acid composition, sunflower oil contains around 48-74 % linoleic acid, whereas that for corn oil is around 34-65%. Linoleic acid is an essential multi-unsaturated fatty acid that cannot be synthesized in the human body, therefore should be definitely consumed externally, by food intake.

Hazelnut oil is also known to be very beneficial for human health. It is one of the rare nutrients, which possess the two important fatty acids -oleic acid and linoleic acid- in its combination.

In the fatty acid composition of hazelnut oil, there is around 71-91% of oleic acid and at around 2-21% linoleic acid. Oleic acid, which is a mono-unsaturated fatty acid, reduces the risk of high blood pressure, fights cholesterol by reducing bad cholesterol, demonstrates preventive impact on cardiovascular diseases, reduces insulin needs of diabetes patients, and most importantly it has preventive power on one of the most serious modern diseases, cancer. The smoke point of hazelnut oil is small compared to other oils. However, it is still high, making hazelnut oil to be applicable for using as frying oil (216 ^{o}C).

1.4 Microwave Frying

Use of microwaves for frying of food products may be considered as a new way of improving the quality of the fried foods. Microwaves offer tremendous advantages in certain food processing operations. Especially in food dehydration, microwaves accelerate the falling rate period, which consequently reduces drying time significantly. However, there has not been much study on the use of microwaves for the frying process. It is expected that the frying process will take less time with the aid of microwaves compared to conventional deep-fat frying. Since it is known that frying time is a significant factor in oil absorption, it is expected that moisture content, color and texture of the fried foods will change in the case of microwave frying process compared to conventional deep-fat frying.

When the food products are subjected to microwaves enhanced moisture loss due to pressure driven flow is observed (Feng and Tang, 1998). Therefore, the evaporation rate is higher in microwave processing. This indicates that in microwave frying, moisture loss will be higher and consequently oil absorption will be higher compared to conventional deep-fat frying. However, the frying time is less in the case of microwave frying which in turn may lead to less oil absorption. So, there is a trade off between the high moisture loss and short frying time.

The effect of microwaves on the fatty acids is an important concern for microwave frying. However it was found out that, microwave heating hardly modified the fatty acid profiles of both chicken and beef patties, whereas frying in olive oil increased oleic and eicosapentaenoic acids and decreased linoleic and docosahexaenoic acids in both types of products (Echarte, Ansorena and Astiasaraä, 2003).

1.5 Osmotic Dehydration Prior to Frying

In recent years, the consumer tendency to consume low-fat snack products has increased significantly. The new fat free tortilla chips are baked rather than fried, however they have different flavor and textural properties as compared to the fried ones (Rickard, Wuerthner and Barret, 1993).

Some alternative methods have been developed to manufacture fried products with reduced fats and less oil uptake during the frying process. Most of the methods were primarily based on coating the foods with hydrocolloids and modified starches (Krokida, Oreopoulu, Maroulis and Marinos-Kouris, 2001a).

Another type of pre-treatment to reduce oil uptake of fried potatoes involves conventional frying with premature removal from the fryer at a high moisture content (~10 %) and finish processing using conventional air drying (Myers, 1990). Super heated steam instead of air has also been used instead of hot air drying (Li-Seyed-Yagoobi, Moreira, and Yamsaengsung, 1999). However, superheated steam drying may cause damage to heat sensitive products and may initiate browning reactions since the product temperature is generally higher than 100 ^{o}C.

As an alternative to air drying, the osmotic pre-treatment of the potatoes by immersion or spraying with sugar or salt solutions has been immersed. Osmotic dehydration is primarily used for partial dehydration of materials through elimination of a large portion of the contained water. At the same time certain solids are infused into the material matrix (Krokida, Oreopoulu, Maroulis and Marinos-Kouris, 2001a). Osmotic dehydration is an effective method to remove water from vegetable tissues while simultaneously introducing solutes in the product (Toringa, Esveld, Scheewe, van den Berg, Bartels, 2001).

Osmotic dehydration as a pre treatment is a good way of producing dried fruits of good quality with reduced energy consumption (Torreggiani, 1993; Sereno, Moreira, and Martinez, 2001). Osmotic dehydration also termed as 'Dewatering and Impregnation Soaking Process' (DISP), is a useful technique for the concentration of fruit and vegetables, realized by placing the solid food, whole or in pieces, in aqueous solutions of sugars or salts of high osmotic pressure (Rault-Wack, 1994; Torreggiani, 1993). In osmotic dehydration, food products are soaked in concentrated aqueous solutions, usually of sugar or salt. During this process, water flows out from the product to the solution and solute in the concentrated sugar/salt solution diffuse into the product. The two main mass transfers continue until the water activity (a_w) of the product and the osmoactive solution are equal (Sahbaz and Uzman, 2000).

In addition, osmotic dehydration is effective at ambient temperature with minimal damaging effect on food quality, achieving product stability, retention of nutrients and improvement of food flavor and texture. It results also in less discoloration of fruits by enzymatic oxidative browning; it satisfies consumers' demand for minimally processed products while additionally facilitates the industrial processes requiring reduced drying times (Kim and Toledo, 1987; Lerici, Pinnavaia, Dalla Rosa, and Bartolucci, 1985; Rault-Wack, 1994; Torreggiani, 1993; Velic´, Planinic´, Tomas, and Bilic´, 2004).

For french fries, sodium chloride solution is recommended to be used in the dehydration process. Since salt is usually added to french fries prior to consumption, soaking them in a sodium chloride solution prior to frying may be a suitable process which can also maintain sensory quality of the product despite some expected textural changes (Andersson, Gekas, Lind, Oliviera, and Öste, 1994; Blahovec, Vacek, and Patocka, 1999).

1.6 Quality Parameters of Fried Potatoes

In general, the four principal quality factors in foods are: (1) appearance, including color, shape, etc.; (2) flavor, including taste and odor; (3) texture; and (4) nutrition (Bourne, 1982).

In fried foods the most important product properties that are measured to determine related quality characteristics and examined in this study are: moisture content, oil content, color and texture.

1.6.1 Moisture and Oil Content

Oil content is one of the most important quality attributes of a deep fat fried product. The texture of a low-oil-content product can be hard and unpleasant. Also, with the growing healthy consciousness of the consumer, demand for lower oil-content fried foods has increased. Therefore, oil contents of products have to be taken into consideration.

Foods with more moisture loss also show more oil uptake during frying (Gamble, Rice and Selman, 1987b). Some even argue that the total volume of oil will be equal to the total volume of water removed (Pinthus, Weinberg and Saguy, 1993).

Oil uptake during deep-fat frying of products is affected by many factors, including oil quality, frying temperature and duration, its composition (e.g. moisture, solids), porosity, pre-frying treatments (e.g., drying, blanching) and coating (Pinthus, Weinberg, and Saguy, 1995b; Selman and Hopkins, 1989; Stier and Blumenthal, 1990).

Since most of the fat is taken up after removal of the food from the oil, the habits of the consumer during removal of the food from the oil can play large role. Proper shaking and draining of the food are important for reducing oil content of the food (Mellema, 2003).

Excess oil absorption may result from low frying temperatures or overloading the fryer beyond its capacity. At low temperatures, there is a tendency to cook food longer to obtain the desired color of the food. Therefore, oil absorption increases (Orthoefer, Gurkin and Liu, 1996). In contrast, Moreira, Castell-Perez and Barrufet, (1999) argued that higher oil temperatures lead to a faster crust formation and so favoring the conditions for oil absorption.

It is well known that oil uptake is a function of the surface area of the food, thus it is obvious that the shape of the food will affect total oil uptake. For instance, samples can be sliced in larger chunks or surface roughness can be reduced by control of the quality of the slicing blades (Mellema, 2003).

As previously mentioned, one of the most often mentioned parameters to reduce oil uptake at the level of the food composition is the moisture content. Pre-drying of foods like potatoes is a common way to reduce oil uptake (Krokida, Oreopoulu, Maroulis and Marinos-Kouris, 2001b).

Since the properties of the surface of the food are most important for oil uptake, the application of a coating is a promising route. Often mentioned properties of coatings in relation to oil uptake are low moisture content, low moisture permeability, thermo-gelling or cross-linked (Mellema, 2003).

There are abundant methods to determine oil content of products. Soxhlet extraction is a simple gravimetric method, in which the oil is extracted from the product using organic solvents. In DSC method, the melting enthalpy is taken as a measure of oil. MRI (Magnetic Resonance Imaging) method relies on the difference in relaxation between solids and liquids (Mellema, 2003). Ufheil and Escher (1996) followed the uptake of oil during deep-fat frying of potato slices by frying slices for an equal length of time, introducing oil soluble and heat stable dye into the oil at different times. Gamble et al. (1987b) investigated the distribution of oil taken up during frying. Samples were fried in red-stained oil and after frying products were photographed.

1.6.2 Color

Color is an important factor influencing consumer acceptability of a fried product. It can indicate high-quality products such as the golden yellow of a potato. Color also influences flavor recognition. Panel evaluation and comparison to standards are the most common approaches for determining color of fried foods. Colorimeters can also be used to determine the color of products objectively. CIE color scale is commonly used to express color differences among samples. The L^* dimension defines the lightness, the a^* refers to the redness or greenness and the b^* dimension refers to the blueness or yellowness.

The consumer generally uses the color of a product in order to determine the end of the frying process. The final color of the fried product depends on the absorption of oil and the chemical reactions of browning of reducing sugars and protein sources (Baixauli, Salvador, Fiszman and Calvo, 2002). Caramelization, involving thermal degradation of sugars without amine participation also takes place during frying process (Baik and Mittal, 2003). Frying temperature and duration are directly effective on color development. Ling, Gennadios, Hanna and Cuppett (1998) found onion rings fried at 190°C had lower L^* values (decreased lightness), higher a^* values (increased redness) and lower b^* values (decreased yellowness) than onion rings fried at 170°C. Furthermore, similar color changes for coated chicken parts with increasing frying times were reported (Waimaleongora-Ek and Chen, 1983). Fried foods are also affected by the type and age of the frying oil (Loewe, 1990). Lee and Dawson (1973) showed that the adsorption of reused corn oil by chicken pieces would undoubtedly affect product quality.

1.6.3 Texture

The term texture is still not well defined in food technology; but it is a very important quality characteristic of the fried product. Texture is a sensory perception, which means that only the human can perceive, describe and quantify it. It is generally a multi parameter attribute, usually associated with mechanical, geometrical and acoustic parameters (Szczesniak, 1988). In products with relatively high content of starch such as potatoes the major influence on texture could be due to gelatinization of starch during heating. The overall texture of a fried product is partially influenced by the composition of a food material. Interactions between proteins, starch, and its components (amylose and amylopectin) are of importance for the final quality of the product (Rovedo, Pedreno-Navorro and Singh, 1999). Varietal characteristics, growing location, cooking conditions and time have also a bearing on the texture properties (Bushway, True, Work and Bushway, 1984) of the foods. İçöz, Şumnu and Sahin (2004) found that increasing microwave power level in baking had increased the hardness of breads. One of the recommended assay to study the texture of fried potatoes is the puncture test which measures the force required to push a probe into a food (Bourne, 2002). Penetration test is also used to measure hardness of the products (İçöz, et. al, 2004).

In this study, hardness of the potato pieces was measured. Hardness was defined as the peak force for the penetration of the probe to the product.

1.7 Taguchi Technique

The experimental design technique of Genichi Taguchi that was devised specifically to improve the quality of Japanese manufactured goods in the post war period in conjunction with analysis of variance (ANOVA) has been extremely successful. Originally applied in the field of engineering, it can be used to optimize any complex process (Dawson and Barnes, 1992). Taguchi design can determine the effect of factors on characteristic properties and the optimal conditions of factors.

The word "design" in "design of experiments" implies a formal layout of the experiments that contains information about how many tests are to be carried out and the combination of factors included in the study. There are many possible ways to lay out the experiment. A number of standard orthogonal arrays (number tables) have been constructed to facilitate designs of experiments. Each of these arrays can be used to design experiments to suit several experimental situations.

Orthogonal arrays are balanced matrices. Pair wise orthogonality is present when all possible combinations of test levels between pairs of columns occur and when each of these possible combinations occur an equal number of times. An example of a frequently used orthogonal array is shown in Table 1.1. This particular balanced matrix is termed orthogonal distribution array L_8 (2^7), more commonly referred to as simply an L_8 orthogonal array (ITT TQM Group, 1992)

Table 1.1 L8 Orthogonal Array

Column	1	2	3	4	5	6	7
Experiment #							
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

The $L_a\ (b^c)$ notation for an orthogonal array can be decomposed as:

L: Symbol for an orthogonal array

a: The number of experiments required for this particular array

b: Specifies the number of experiments required for the particular array

c: Specifies the number of factors which the array can examine

Depending on the number of factors and factor levels several orthogonal arrays have been designed (Table 1.2).

Table 1.2 Taguchi Orthogonal Arrays

2-level (fractional factorial) arrays

$L_4(2^3)$, $L_8(2^7)$, $L_{16}(2^{15})$, $L_{32}(2^{31})$, $L_{64}(2^{63})$

2-level array

$L_{12}(2^{11})$ (Plackett-Burman Design)

3-level arrays

$L_9(3^4)$, $L_{27}(3^{13})$, $L_{81}(3^{40})$

4-level arrays

$L_{16}(4^5)$, $L_{64}(4^{21})$

5-level array

$L_{25}(5^6)$

Mixed-level arrays

$L_{18}(2^1x3^7)$, $L_{32}(2^1x4^9)$, $L_{50}(2^1x5^{11})$

$L_{36}(2^{11}x3^{12})$, $L_{36}(2^3x3^{13})$, $L_{54}(2^1x3^{25})$

The set of balanced matrix experiment consists of a set of experimental conditions where the settings of multiple product and/or process parameters are purposely changed. After conducting a matrix, experiment the data collected from these experiments can be analyzed to separate and to quantify the size and direction of the effects that each product and process parameter had on the system. Conducting these balanced experiments using orthogonal arrays allows studying the effects of several parameters via a small number of experiments (ITT Quality Management Group, 1992).

Orthogonal arrays and ANOVA are used as the tools of analysis for Taguchi Technique. ANOVA can estimate the effect of a factor on the characteristic properties and experiment can be performed with the minimum replication using the orthogonal arrays. Conventional statistical experimental design can determine the optimal condition on the basis of the measured values of the characteristic properties while Taguchi method can determine the experimental condition having the least variability as the optimal condition. The variability is expressed by signal to noise (S/N) ratio. The experimental condition having the maximum S/N ratio is considered as the optimal condition as the variability characteristics is inversely proportional to the S/N ratio (Roy, 1990).

The traditional method of calculating average factor effects and thereby determining the desirable factor levels (optimum condition) is to look at the simple averages of the results. Although average calculation is relatively simple, it doesn't capture the variability of results within a trial condition. A better way to compare the population behavior is to use the mean-squared deviation, which combines effects of both average and standard deviation of the results. For convenience of linearity and to accommodate wide-ranging data, a logarithmic transformation of MSD (called the signal-to-noise ratio) is recommended for analysis of results. When the S/N ratio is used for results analysis, the optimum condition identified from such analysis is more likely to produce consistent performance.

1.8 Response Surface Methodology (RSM)

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes. It also has important applications in the design, development, and formulation of new products as well as in the improvements of existing product design (Myers and Montgomery, 2002).

Response surface methods are used to examine the relationship between one or more response variables and a set of quantitative experimental variables or factors. Designs of this type are usually chosen when curvature is supposed to be present in the response surface.

RSM is a four step process. First, the number of factors that are of interest are determined. Second, the ranges 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 tested. Fourth, the data from these experiments are analyzed by RSM and then interpreted. For RSM to be meaningful certain assumptions should be satisfied (Myers and Montgomery, 2002). These assumptions are:

1. The factors which are of critical to the product are known
2. Adequate coverage of the region of interest on the response surface should be ensured.
3. The factors should vary continuously throughout the experimental region.
4. A mathematical relation that relates the factors to the response should exist.
5. The response defined by the above function should be a smooth surface.

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 fit, but still provide evidence regarding the importance of a second-order contribution or curvature.

Box-Behnken designs are proper to be used when performing non-sequential experiments. That is, when it is planned to perform the experiment once. These designs allow efficient estimation of the first- and second-order coefficients. Since Box-Behnken designs have fewer design points, they are less expensive to run than central composite designs with the same number of factors. Box-Behnken designs can also prove useful if the safe operating zone for process is known.

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. Box-Behnken designs do not have axial points, thus, it is ensured that all design points fall within the safe operating zone. Box-Behnken designs also ensure that all factors are never set at their high levels simultaneously.

Box-Behnken designs are fractional 3^k factorial designs. The designs either meet, or approximately meet, the criterion of rotatability. These designs are formed by combining two-level factorial designs with incomplete block designs.

In performing designed experiments there are often several responses of interest. Additionally, to optimize these responses individually may yield different and conflicting factor settings. For instance, in all consumer products (food, tobacco), the scientist must deal with taste as a response but also must consider undesirable by-products. In the pharmaceutical or biomedical area, the clinician is primarily concerned with the efficacy of the drug or remedy but must not ignore the possibility of serious side effects (Myers and Montgomery, 2002).

Simultaneous consideration of multiple responses involves first building an appropriate response surface model for each response and then trying to find a set of operating conditions that in some sense optimizes all responses or at least keeps them in desired regions. In this study multiple response optimization was performed by using the response optimizer option of MINITAB.

Joint optimization must satisfy the requirements for all the responses in the set. The overall desirability (D) is a measure of how well the combined goals for all the responses have been satisfied. Overall desirability has a range of zero to one. One represents the ideal case; zero indicates that one or more responses are outside their acceptable limits.

The optimization is accomplished by

1. Obtaining the individual desirability (d) for each response
2. Combining the individual desirabilities to obtain the combined or composite desirability (D).
3. Maximizing the composite desirability and identifying the optimal input variable settings

MINITAB obtains an individual desirability (d) for each response[1] using the goals and boundaries that are provided. There are three goals to choose from. It may be desired:

- Minimize the response (smaller is better)
- Target the response (target is best)
- Maximize the response (larger is better)

---

[1] If there is only one response, the overall desirability is equal to the individual desirability.

In MINITAB's approach to optimization, each of the response values is transformed using a specific desirability function. The weight defines the shape of the desirability function for each response. For each response, a weight can be selected from 0.1 to 10 to emphasize or de-emphasize the target. A weight;

- Less than 1 (minimum is 0.1) places less emphasis on the target
- Equal to 1 places equal importance on the target and the bounds
- Greater than 1 (maximum is 10) places more emphasis on the target

After MINITAB calculates an individual desirability 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 (D) 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.

It is essential to assess the importance of each response in order to assign appropriate values. Importance values must be between 0.1 and 10. If all responses are equally important, the default value of 1.0 can be used for each response. The composite desirability is then the geometric mean of the individual desirabilities.

1.9 Objectives of the Study

The tendency to consume low fat foods has increased tremendously nowadays. As a result, researchers try to find out ways to reduce oil content of the fried foods.

To reduce oil content of the fried potatoes, various methods has been proposed. However, there is no scientific literature about microwave frying as an alternative to conventional frying to reduce oil content of the foods. Microwaves offer tremendous advantages to many food processes. In frying, microwaves reduce the frying time and in that respect microwave frying will be more economical. Microwaves may also improve the quality parameters of the fried potatoes.

Moreover there is no study on the use of *Taguchi Technique* as an optimization method for food processes. This study will be a unique one in that respect. Taguchi technique is an easy optimization technique that is applicable for food process. The technique enables the use of qualitative variables in the experimental design. In that respect it is more advantageous than Response Surface Methodology (RSM) which is commonly used in food processes. RSM uses regression models which may not be sufficient to explain the variability due to qualitative variables.

This study is divided into two parts. The objective of the first part of the study is to optimize the microwave frying of potato slices using Taguchi Technique by considering the effects of microwave power, oil type and frying time on quality parameters of fried potatoes. In the second part of the study, it was aimed to evaluate the effect of osmotic dehydration on microwave frying process, and to optimize the process by using two different optimization techniques which were Taguchi Technique and Response Surface Methodology. Finally the efficiency of the two different statistical optimization methods was compared.

CHAPTER 2

MATERIALS AND METHODS

2.1 Preparation of potato slices

Potatoes were peeled, washed and cut by using a manually operated cutting device into disc shaped slices of 5 mm in thickness and 3.5 cm in diameter. The uniformity of thickness of slices was checked using a caliper (Mitutoyo, Japan). The slices were washed to remove free starch and surface was blotted with a paper towel before frying. Three different types of oil used in the study were sunflower oil (Bizim Yağ, Ülker, İstanbul), corn oil (Aymar, Aymar Yağ Sanayii, İstanbul) and hazelnut oil (Çotanak, Ordu Soya Sanayii, Ordu).

2.2 Methods

This study was divided into two parts. In the first part of the study, microwave frying conditions were optimized by considering the effect of microwave power level, frying time and oil type on product quality. In the second part, the effect of osmotic dehydration on microwave frying was evaluated and the frying process was optimized by considering the effect of microwave power level, frying time and osmotic dehydration time on product quality.

2.2.1 Effects of microwave frying on the quality parameters of potato slices

2.2.1.1 Frying

Microwave frying was conducted in a domestic microwave oven (Arçelik, Turkey). Three power levels, 400W, 550W, 700W were used in the experiments. Power levels were determined by IMPI 2-L test (Buffler, 1993) Microwave frying was performed using a glass container containing 400 mL oil. First, the oil which is at room temperature is heated to a temperature of 170±1^{o}C at the maximum power level of the microwave oven (800 W). Then, potato slices were placed in hot oil and frying was performed at a specified microwave power and time. Seven pieces of potatoes were fried in each experiment. The oil was replaced after frying in three different conditions.

Three different types of oil, sunflower, corn and hazelnut oil were used in this part of the study. In addition to oil type and microwave power level, a third factor in the experimental design was the frying time. The potatoes were fried for 2.0, 2.5 and 3.0 minutes.

As control, conventional deep fat frying was conducted at a temperature of 170±1^{o}C in commercial bench-top deep fat fryer (TEFAL, France) containing 400 mL sunflower oil. Samples were fried for 4.5 min. Potato oil ratio was kept same as 0.0675 (w/v) in both microwave and conventional deep-fat frying.

2.2.1.2 Orthogonal array and experimental parameters (Taguchi Design)

For Taguchi design and subsequent analysis, the software named as Qualitek-4 (Version 4.82.0) was used. The appropriate orthogonal array for the experiment was determined by the software. Since the interactions between the factors are also sought for, an L27 array was chosen by the program. This means that 27 experiments with different combinations of the factors should be conducted in order to study the main effects and interactions. It is important to note that the design is also a full factorial design (3^3=27). However, in general, Taguchi design is preferred since it reduces the number of experiments significantly. But in this study, since it is sought to observe all the interaction effects between the factors as well, the resulting Taguchi design became a full factorial design. Table 2.1 shows the parameters and levels used. Table 2.2 shows the 27 trial conditions to be performed.

It is important to mention that the experiments were not conducted in the order described in Table 2.2. To provide randomness, the experiments were performed depending on the order determined by the software. Each experiment was carried out twice in different times.

Table 2.1 Parameters and levels used in the first part of the study

	Levels		
Parameters	1	2	3
Microwave Power (W)	400	550	700
Frying Time (min)	2.0	2.5	3.0
Oil Type	Sunflower	Corn	Hazelnut

Table 2.2 Experimental conditions for the 1st part of the experiment (Taguchi Design)

Exp. No.	MW Power	Frying Time (min)	Oil Type	Exp. No.	MW Power	Frying Time	Oil Type
1	400	2.0	S.F[a]	15	550	2.5	Nut
2	400	2.0	Corn	16	550	3.0	S.F
3	400	2.0	Nut	17	550	3.0	Corn
4	400	2.5	S.F	18	550	3.0	Nut
5	400	2.5	Corn	19	700	2.0	S.F
6	400	2.5	Nut	20	700	2.0	Corn
7	400	3.0	S.F	21	700	2.0	Nut
8	400	3.0	Corn	22	700	2.5	S.F
9	400	3.0	Nut	23	700	2.5	Corn
10	550	2.0	S.F	24	700	2.5	Nut
11	550	2.0	Corn	25	700	3.0	S.F
12	550	2.0	Nut	26	700	3.0	Corn
13	550	2.5	S.F	27	700	3.0	Nut
14	550	2.5	Corn				

[a] S.F: Sunflower

2.2.2 Effects of osmotic dehydration and microwave power level on the quality parameters of microwave fried potato slices

2.2.2.1 Osmotic Dehydration Treatment

In the second part of the study instead of oil type, osmotic dehydration time was used as the third factor in the experimental set up. The potatoes were immersed in salt solution (20 % w/w) at 30 °C for 15, 30, 45 minutes. Seven pieces of potatoes were soaked in 200 ml of salt solution at a ratio of salt solution to potato pieces of 7.5:1 (w/w). Potatoes were gently blotted dry with paper towel to remove surface solution prior to frying.

2.2.2.2 Conventional drying

In order to understand the effect of salt which diffused into the potato, the potatoes were pre-dried to the same level of moisture content as osmotic dehydration. The drying was performed in the forced convection oven at 105°C .

2.2.2.3 Frying

Frying was conducted in the conditions described in the first part of the study. However, the osmotically dehydrated potatoes were fried at the predetermined microwave power levels (400 W, 550 W, 700W) for 1.5, 2.0, 2.5 minutes respectively. For comparison, osmotically dehydrated potatoes were also conventionally fried at 170 ±1 °C in commercial bench top deep fat fryer for 4 minutes.

2.2.2.4 Orthogonal array and experimental parameters (Taguchi Design)

The orthogonal array was the same as the one in the first part. However the parameters and their levels have changed. The parameters and the experimental conditions are presented in Table 2.3 and 2.4 respectively.

Table 2.3 Parameters and levels used in the second part of the study

	Levels		
Parameters	1	2	3
Microwave Power (W)	400	550	700
Frying Time (min)	1.5	2.0	2.5
Osmotic Dehydration Time (min)	15	30	45

Table 2.4 Experimental conditions for the 2nd part of the experiment (Taguchi Design)

Exp. No.	MW Power	Frying Time (min)	OD[a] Time (min)	Exp. No.	MW Power	Frying Time	OD Time
1	400	1.5	15	15	550	2.0	45
2	400	1.5	30	16	550	2.5	15
3	400	1.5	45	17	550	2.5	30
4	400	2.0	15	18	550	2.5	45
5	400	2.0	30	19	700	1.5	15
6	400	2.0	45	20	700	1.5	30
7	400	2.5	15	21	700	1.5	45
8	400	2.5	30	22	700	2.0	15
9	400	2.5	45	23	700	2.0	30
10	550	1.5	15	24	700	2.0	45
11	550	1.5	30	25	700	2.5	15
12	550	1.5	45	26	700	2.5	30
13	550	2.0	15	27	700	2.5	45
14	550	2.0	30				

[a] OD Time: Osmotic Dehydration Time

2.2.2.5 Response Surface Design

In this study, due to number of factors and their levels, RSM was performed by using a Box-Behnken design. The design consisted of 14 runs: 12 factorial, 2 center runs. The uncoded and coded independent variables are given in Table 2.5. The experimental design is given in Table 2.6.

Table 2.5 Description of the variables for RSM design

Independent Variable	Coded Levels		
	-1	0	+1
	Factor Levels		
Microwave Power (W)	400	550	700
Frying Time (min)	1.50	2.00	2.50
Osmotic Dehydration Time (min)	15	30	45

Table 2.6 Experimental design for RSM design

MW Power	Frying Time	OD Time
-1	-1	0
1	-1	0
-1	1	0
1	1	0
-1	0	-1
1	0	-1
-1	0	1
1	0	1
0	-1	-1
0	1	-1
0	-1	1
0	1	1
0	0	0
0	0	0

2.2.3 Measurement of temperature

In order to measure the temperature at the center of the potatoes, fiber optic temperature probes and FISO real time measurement system (FISO Technologies, Inc, Quebec, Canada) were used.

2.2.4 Viscosity measurement

The viscosities of the oils were measured with a rotational viscometer (Visco Elite-R, Fungilab, Spain) equipped with the low viscosity adapter (LCP), which had a Searle-type concentric cylinder configuration. The sample was sheared at a constant shear rate of $61.18 s^{-1}$ (50 rpm) for 5 minutes.

2.2.5 Water activity (a_w) measurement

The water activity of the osmotically dehydrated raw potatoes was measured with a water activity meter (Aqualab LITE, WA, and U.S.A). The instrument was calibrated with standard salt solutions of NaCl.

2.2.6 Analysis of fried samples

The fried samples were dried in a forced convection oven at 105^oC (Nüve, Turkey) up to the establishment of constant weight for moisture determination (AOAC, 1984).

The oil content of the fried samples was determined by using Soxhlet extraction method with n-hexane for 6 hours after the potatoes were dried in the conventional oven (AOAC, 1984).

Moisture content and oil content were calculated on % dry basis (g moisture/ g dry solid, g oil/g dry solid).

Color of the fried samples was measured using a Minolta color reader (CR-10, Japan). The color readings were expressed by CIE (L*a*b*) color system. L*, a* and b* indicates whiteness/darkness, redness/greenness, blueness/yellowness values, respectively. Total color difference (ΔE) was calculated from the following equation;

$$\Delta E = \sqrt{\left[(L^* - L_{standard}^*)^2 + (a^* - a_{standard}^*)^2 + (b^* - b_{standard}^*)^2\right]}$$

where, standard values referred to the $BaSO_4$ plate (L^*=96.9, a^*=0 and b^*=7.2). Triplicate readings were carried out at room temperature at three different locations of each sample and mean value was recorded.

Textures of the samples were determined in terms of hardness. Hardness of the potato samples were measured 15 min after frying, using a texture analyzer (Lloyd Instruments, TA Plus, Hants, UK) directly without any sample preparation. A pin shaped probe was attached to the instrument for the penetration test. The instrument was set to a speed of 55 mm/min for 100% penetration of the pin into the fried sample. Hardness was defined as the peak force for this penetration. Fig. A.1 shows a sample TPA curve for a microwave fried potato.

2.2.7 Statistical analysis and optimization

For each of the quality parameters three-way ANOVA was conducted by using the statistical software program MINITAB for Windows (Version 14) to find out which parameters are significant for the specified quality parameter. After conducting ANOVA, the assumptions for ANOVA to be valid were checked. These assumptions were normality and constant variance assumptions of the residuals. The normality assumption was checked by Anderson-Darling test. The constant variance assumption was checked by Bartlett's test. If either normality or constant variance assumption was not satisfied for residuals, transformation was performed to solve the problem. When significant difference was found between different levels of the parameters, the treatments were compared using Tukey's test ($p \leq 0.05$).

For optimization by Taguchi Technique, the software, Qualitek-4 (Version 4.82.0), which is designed for Taguchi experiments, was used. When a product or process under study is to satisfy more than one objective, performance of samples tested for each trial condition are evaluated by multiple criteria of evaluation. Such evaluations can be combined into a single quality, the overall evaluation criterion (OEC) that is considered as the result for the sample. But the evaluation of each individual criterion may have different units of measure, quality characteristics and relative weighting. In order to combine different criteria they must be first normalized and weighted accordingly (Roy, 2001). In this study there were four criteria, which were moisture content, oil content, color and texture respectively. For optimization these four criteria's quality characteristics, best and worst values should be determined and be assigned a relative weighting for the parameters depending on the importance of that parameter in consumer's mind. The quality characteristics can be of three types: The Larger the Better, The Smaller the better, and The Nominal the best.

For optimization by Response Surface Methodology "multiple response optimizer" option of MINITAB was used. The contour plots for the parameters were also drawn by using MINITAB.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Effects of microwave frying on the quality parameters of potato slices

3.1.1 Moisture Content

The initial moisture content of potatoes was in the range 80-82% on wet basis (449.1 % db on average). It was observed that moisture loss of fried potatoes increased as power level and frying time increased for all types of oils (Fig. 3.1-3.3). The experimental data are available in Table B.1 in Appendix.

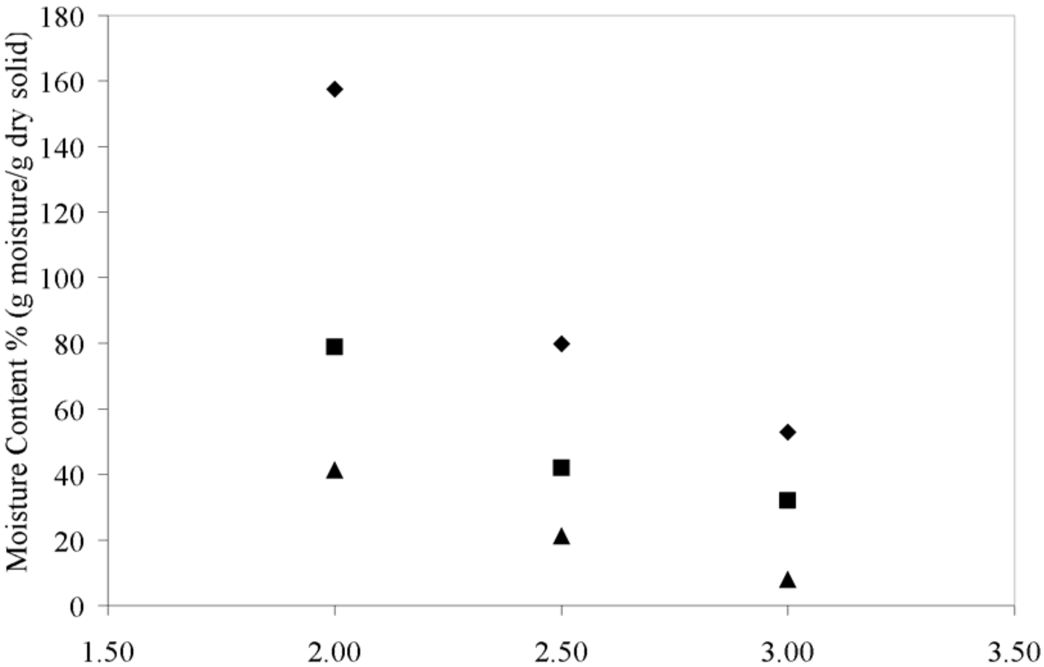

Figure 3.1 Variation of moisture content of potatoes fried in sunflower oil with different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

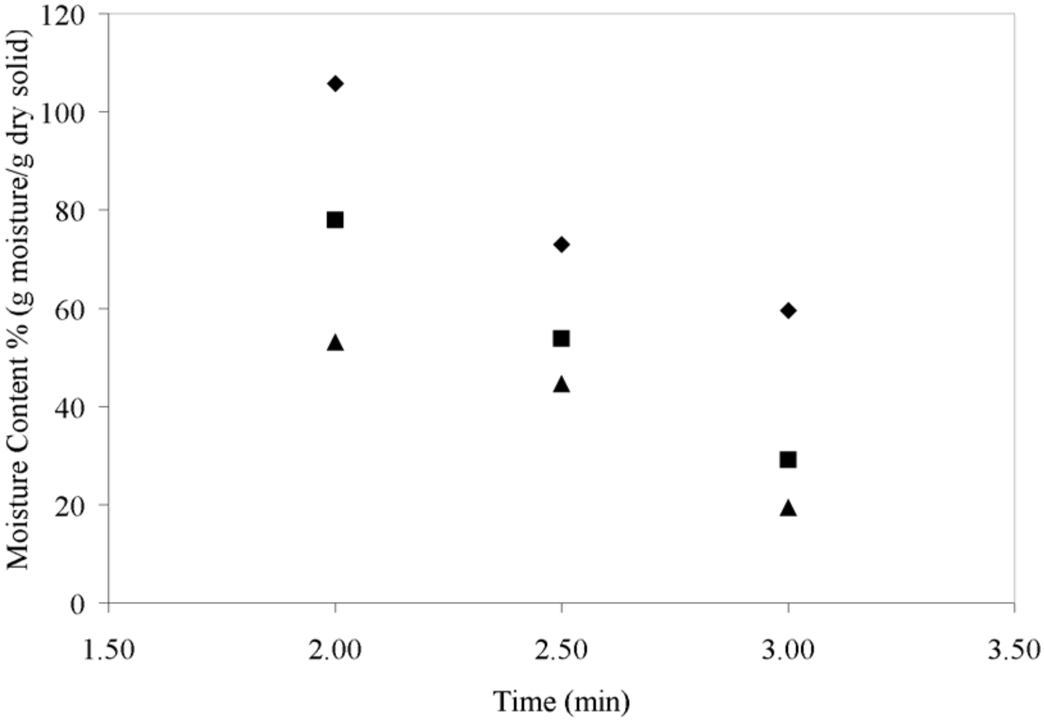

Figure 3.2 Variation of moisture content of fried potatoes fried in corn oil with different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

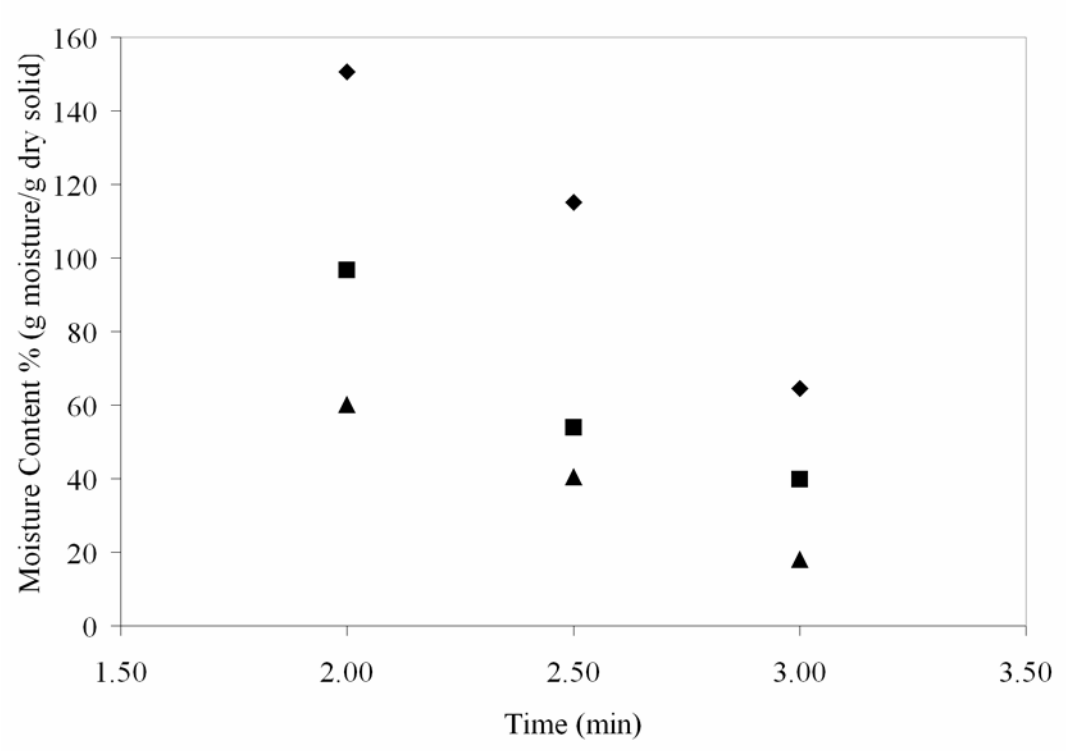

Figure 3.3 Variation of moisture content of potatoes fried in hazelnut oil with different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

When ANOVA was performed, it was seen that the residuals for the moisture content (db) were far away from satisfying the assumption of normality and constant variance which is a required condition for ANOVA to be meaningful. Therefore, transformation was performed to satisfy assumptions. A common transformation used in such cases is Box-Cox transformation. Box-Cox transformation is a useful class of transformation to transform a response to correct non-normality or constant variance assumption. It is a power transformation, y^{λ} where λ is a parameter to be determined. Box-Cox showed how λ can be estimated using method of maximum likelihood. The λ value for the moisture content data was found by using MINITAB 14, and it was found to be 0.29. The transformed form of the moisture content data satisfied the assumptions. In ANOVA and further optimization studies *Moisture Content*$^{0.29}$ values were used.

Table 3.1 Analysis of Variance Results for the quality parameters

Source	d.f.	Moisture Content (%)	Oil Content (%)	Color (ΔE)	Hardness (N)
		p	p	p	p
MW Power	2	0.0000	0.0000	0.0010	0.0000
Frying Time	2	0.0000	0.0000	0.0000	0.0000
Oil Type	2	0.1340	0.0000	0.0380	0.0000
MW Power X Frying Time	4	0.0030	0.7370	0.7470	0.0190
MW Power X Oil Type	4	0.0000	0.1030	0.0310	0.0050
Frying Time X Oil Type	4	0.0000	0.2170	0.4260	0.5170
MW Power X Frying Time X Oil Type	8	0.0050	0.6110	0.9990	0.0000
Error	27				
Total	53				

When the ANOVA results in Table 3.1 was examined, it was seen that the most significant main factors on affecting moisture content were microwave power and frying time ($p < 0.05$). The oil type was found to be insignificant on affecting moisture content ($p > 0.05$). This may be explained by the similarity of the dielectric properties of sunflower, corn and hazelnut oils. Since the dielectric properties are known to affect the heating rate in the microwave oven, potatoes fried in different oils may have been heated and lost moisture at the same rate. The similarity between temperature profiles of potatoes during frying supports this idea (Fig. 3.4). The cycling of temperatures seen in Fig. 3.4 is due to the on-off cycling of microwaves.

In terms of interactions between the factors, microwave power-frying time and microwave power-oil type interactions and frying time-oil type interactions were found to be significant ($p<0.05$) (Table 3.1). The three way interactions of the factors were also found to be significant. The detailed ANOVA table is available in Table B.2

According to Tukey test results (Table B.6), there was significant difference between levels of microwave power and frying time in terms of moisture content. In Appendix a table is available that summarizes Tukey test results for all of the quality parameters (Table B.10).

The lowest moisture content was obtained when potatoes were fried at the highest microwave power level (700 W) for the longest frying time (3.0 min) for all oil types. The moisture content of potatoes fried in microwave oven even at low power level (400 W) for 3 min were lower for sunflower, corn and hazelnut oil (52.89 %, 59.56%, 64.55 %) as compared to those fried conventionally (67.44%). The resulting difference between conventional deep-fat frying and microwave frying was expected since microwaves enhance moisture loss significantly. Various researchers have shown that microwave dried vegetables lost more moisture than conventionally dried ones (Sharma and Prasad, 2001; Sumnu, Turabi and Oztop, 2005).

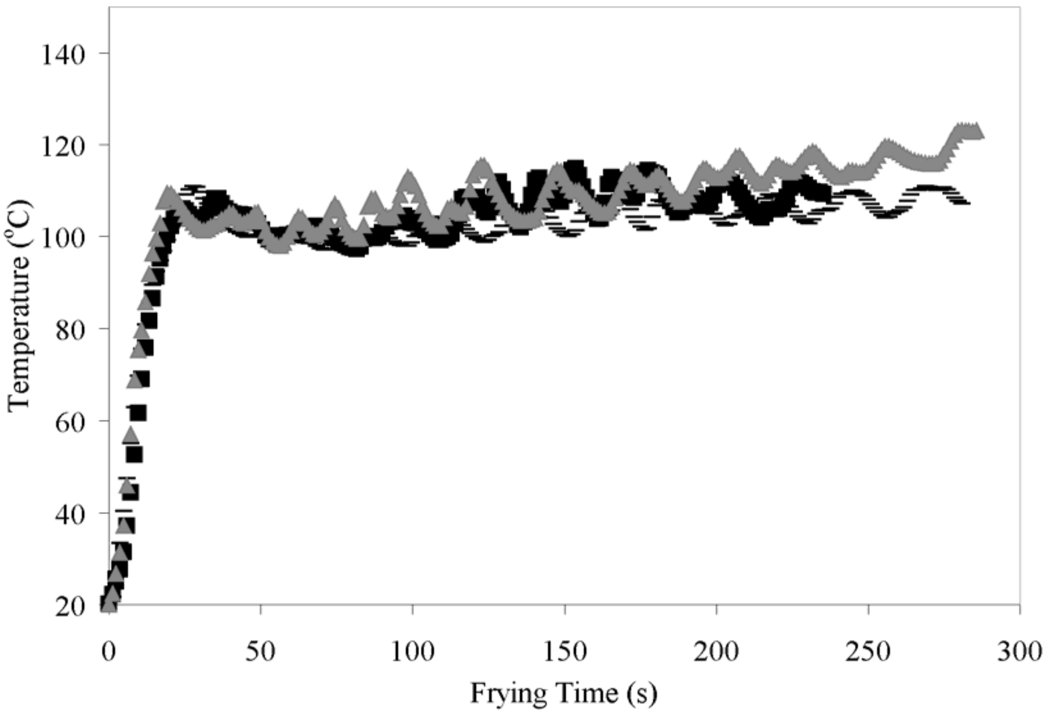

Figure 3.4 Variation of center temperature of potatoes fried at the 550 W microwave power level in different oil types. (♦) Sunflower oil; (▲) Corn oil; (—) Hazelnut oil.

3.1.2 Oil Content

Oil content is one of the most important quality attributes of a deep-fat fried product. The texture of a low-oil-content product can be soft and unpleasant. However, the high oil content is costly to the processor and results in an oily and tasteless product (Moreira, et. al, 1999). Fig. 3.5-3.7, show how oil content change with respect to frying time on the basis of microwave power levels for different oil types. It is common for the three oil type that as microwave power level and frying time increased the oil content of the fried samples increased. Foods with more moisture loss also show more oil uptake. Some even argue that the total volume of oil uptake will be equal to the total volume of water removed (Pinthus, Weinberg and Saguy, 1993). Although microwave frying resulted in high moisture loss even at low power levels, lower oil uptake in microwave frying process was observed as compared to conventional frying. For example, the oil content of potatoes fried at the lowest microwave power level, 400 W for 3 min were 25.48, 29.05, 68.98 % for sunflower, corn and hazelnut oil respectively while it was 41.28 %, 37.22 %, 71.82 % for conventionally fried ones. In other words, microwave fried potatoes had lower oil contents compared to conventionally fried ones. The short frying time may be responsible for this. This may also be explained by the high evaporation rate of water compared to diffusion of oil into the potato due to pressure driven force that is generated by microwaves.

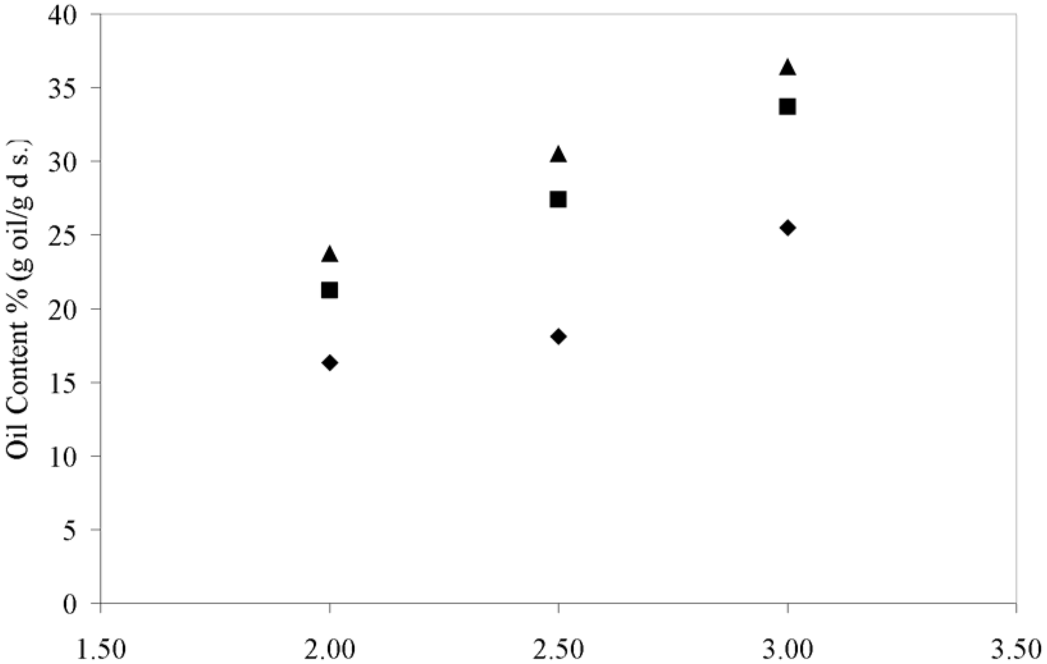

Figure 3.5 Variation of oil content of potatoes fried in sunflower oil with different microwave power levels: (♦) 400W; (■) 550 W; (▲) 700 W.

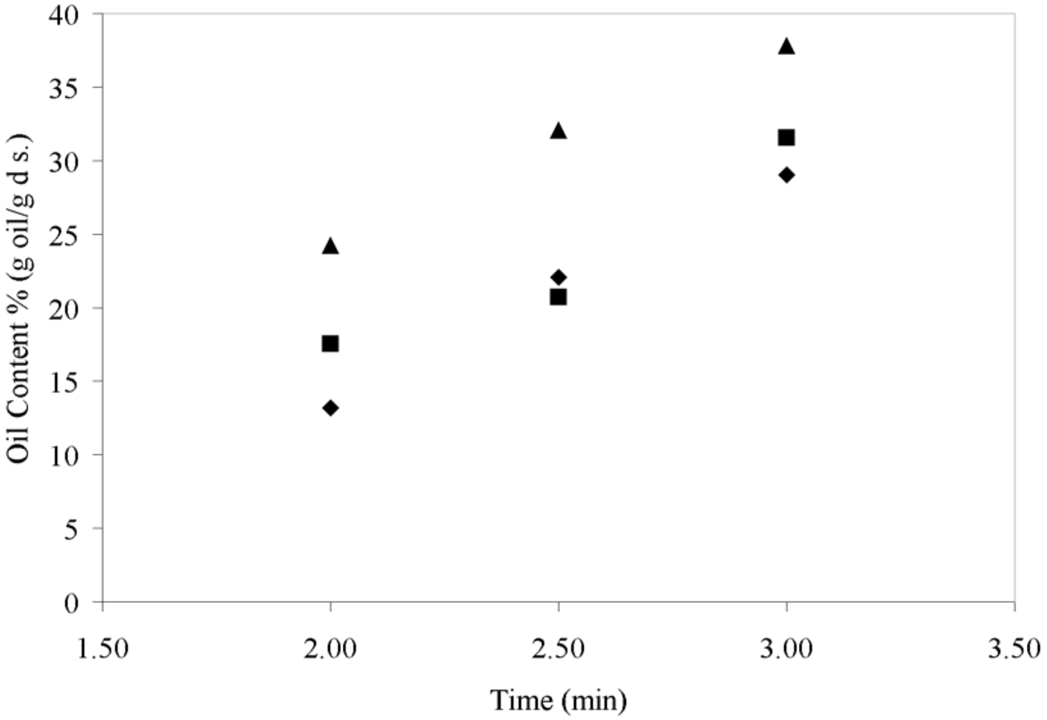

Figure 3.6 Variation of oil content of potatoes fried in corn oil with different microwave power levels: (♦) 400W; (■) 550 W; (▲) 700 W.

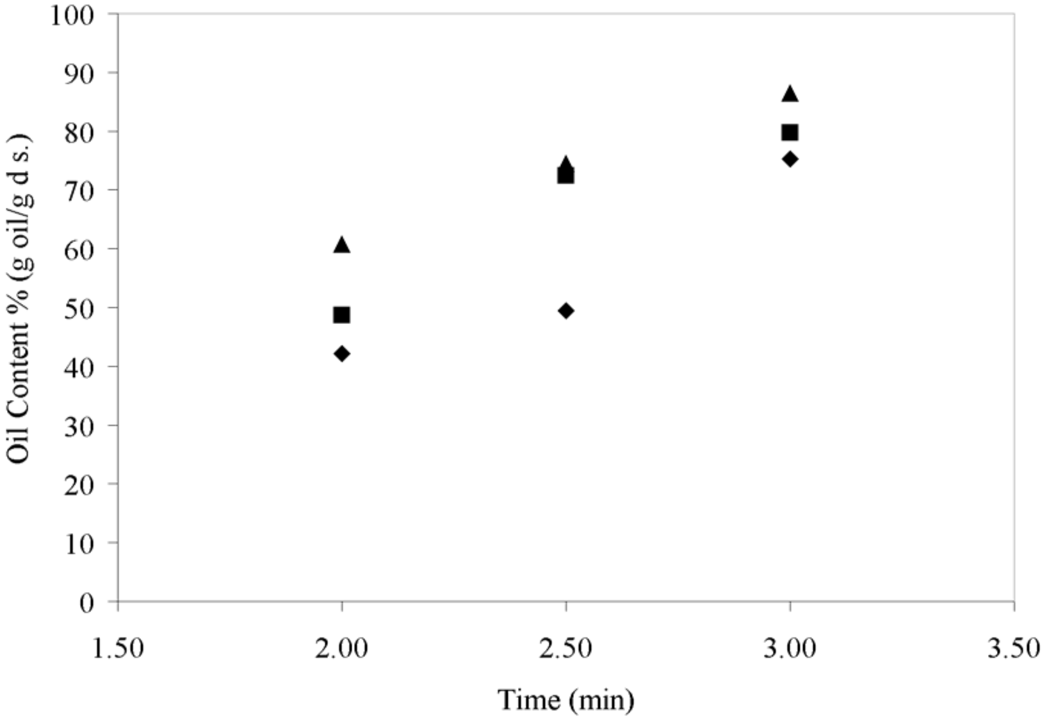

Figure 3.7 Variation of oil content of potatoes fried in hazelnut oil with different microwave power levels: (♦) 400W; (■) 550 W; (▲) 700 W.

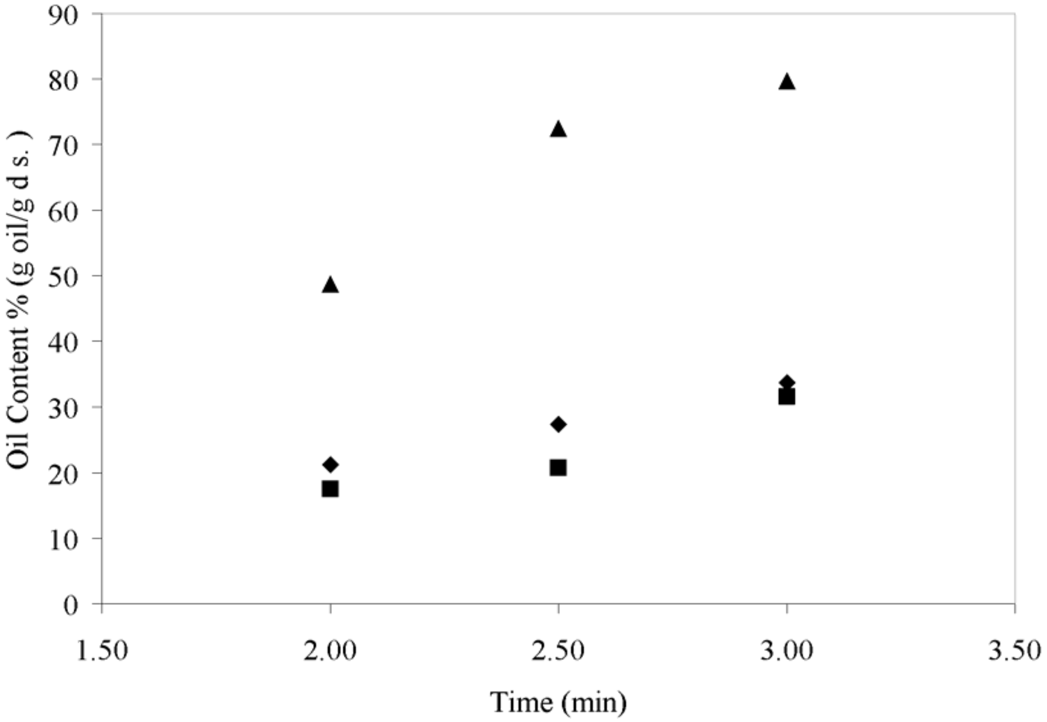

Figure 3.8 Variation of oil content of potatoes fried at the 550 W microwave power level in different oils. (♦) Sunflower oil; (■) Corn oil; (▲) Hazelnut oil.

Fig. 3.8 shows the effects of oil types on oil contents of potatoes fried at 550W microwave power level. Potatoes fried in the hazelnut oil had significantly higher oil content than the ones fried in sunflower and corn oils. The same results were obtained in the other power levels as well. Therefore, it can be concluded that the potatoes fried in hazelnut oil are far away from satisfying consumer's needs in terms of its high calorie.

In order to investigate whether the mechanism of microwave or the properties of hazelnut oil was responsible for higher oil content of fried potatoes, conventional deep fat frying was also conducted for corn and hazelnut oil as well.

The oil contents of potatoes were found as 41.28 %, 37.22 %, and 71.82 % for sunflower, corn and hazelnut oil, respectively. Since oil content of potatoes fried in hazelnut oil were higher than the ones fried in other oil types also in conventional fryer also, it was concluded that microwave effect was not responsible for causing higher oil contents in potatoes fried in hazelnut oil.

Gamble, Rice and Selman (1987a) suggested that most of the oil enters the final product from the adhered oil being pulled into the product when it is removed from the fryer due to condensation of steam producing vacuum. Moreira, Sun and Chen (1997) also observed that only 36 % of the final oil content was absorbed by the tortilla chips during frying and 64 % during cooling leaving only 36 % at the chip's surface. It was also observed that the higher the viscosity of oil could cause the oil to adhere to the products surface (Moreira, Sun and Chen, 1997). Therefore, the viscosities of the sunflower, corn and hazelnut oils were measured and found to be 42.67 cP, 43.72 cP and 54.94 cP at room temperature, respectively. Boyacı, Tekin, Çizmeci and Javidipour (2002), also found out that viscosity of hazelnut oil was higher compared to sunflower and corn oils. According to this result, the higher oil contents of potatoes fried in hazelnut oil may be explained by more accumulated oil at the surface due to its high viscosity.

When ANOVA was performed it was seen that the residuals for the oil content (db) were far away from satisfying the assumption of normality and constant variance similar to moisture content. Therefore, transformation was performed to satisfy the assumptions. Box-Cox transformation was employed again. The λ value for the oil content data was found by using MINITAB 14, and it was found to be -0.23. The transformed form of the oil content data satisfied the assumptions. In ANOVA and further optimization studies $\mathit{Oil\ Content}^{-0.23}$ values were used.

When the ANOVA results in Table 3.1 were examined it was seen that microwave power level, frying time and oil type are all significant on affecting the oil content ($p<0.05$). However, all two-way interactions and the three-way interaction were found to be insignificant ($p>0.05$). The detailed ANOVA table is available in Table B.3.

According Tukey test results (Table B.7), no significant difference in terms of oil content is detected between sunflower and corn oil whereas hazelnut was found to be significantly different from the other two. It is very well known that there is an inverse relationship between moisture and oil contents. While the moisture is evaporated, oil enters the product during frying. However, the effect of oil type on oil content was found to be significant while this was not the case in moisture content. Like microwave frying in conventional frying, the oil type was found to be insignificant on moisture content as well ($p<0.05$). This also explains that most of the oil uptake occurred during cooling.

3.1.3 Color

Color is an important factor influencing consumer acceptance of a fried product. It can indicate high-quality products such as the golden yellow of a potato. The consumer generally uses the color of a product in order to determine the end of the frying process. The final color of the fried product depends on the absorption of oil and the chemical reactions of browning of reducing sugars and protein sources (Baixauli, Salvador, Fiszman and Calvo, 2002).

The total color difference (ΔE) of potatoes increased as microwave power level and frying time increased (Fig. 3.9). As microwave power level increases the temperature of the frying oil increases, which in turn increases the rate of non-enzymatic browning reactions. Consequently the color of potatoes becomes darker.

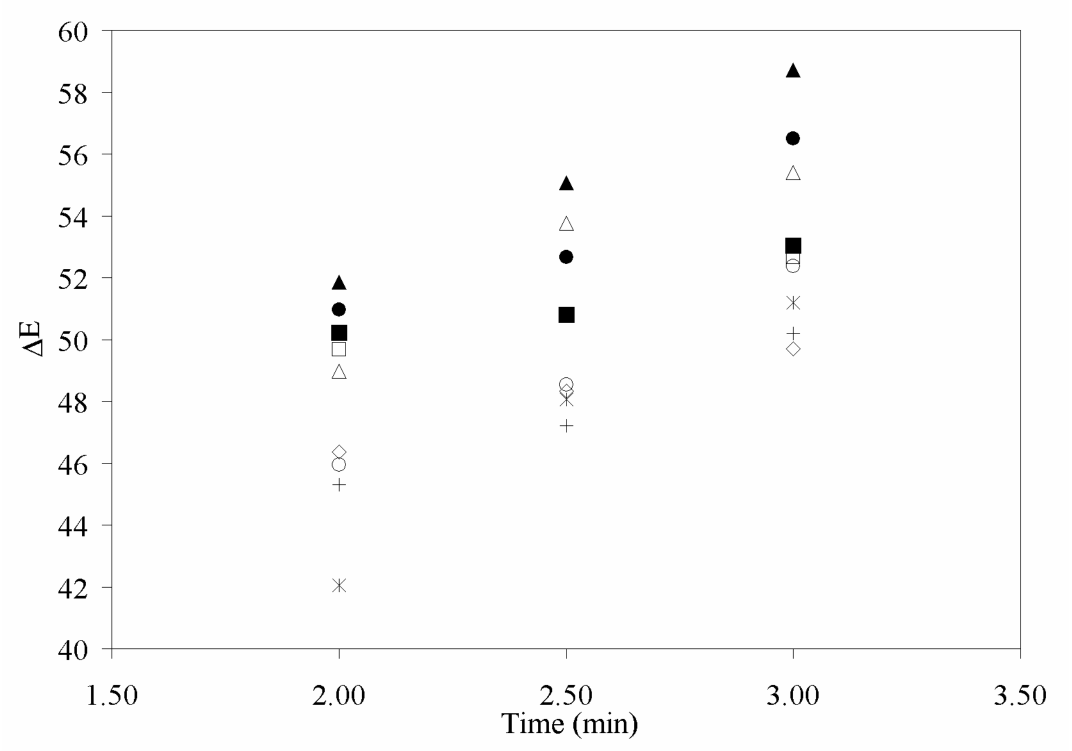

Figure 3.9 Variation of ΔE of the potatoes during frying at different microwave power levels and oil types. (■) 700W-Sunflower Oil; (▲) 700W- Corn Oil; (●), 700W-Nut Oil; (□) 550W- Sunflower Oil; (Δ), 550W-Corn Oil; (O), 550W-Nut Oil; (✱) 400W-Sunflower Oil; (◇) 400W-Corn Oil; (+) 400W-Nut Oil.

According to ANOVA results for the ΔE values it was seen that microwave power level, frying time and oil type are all significant in total color difference ($p<0.05$) (Table 3.1). Among the interactions, except the microwave power-oil type interaction, the other two way interactions and three way interactions were found to be insignificant ($p>0.05$). There were no significant difference between corn and sunflower oil whereas there was significant difference between hazelnut oil and other oil types in terms of ΔE according to Tukey test (Table B.8) ($p<0.05$).

The lightness (L^*) value decreased as microwave power level and frying time increased due to increase in temperature (Fig. 3.10). However, a^* and $b*$ values generally showed an increase as frying time increased in accordance with the results of Krokida, Oreopoulou, Maroulis, Marinos-Kouris (2001c) (Figure 3.11-12).

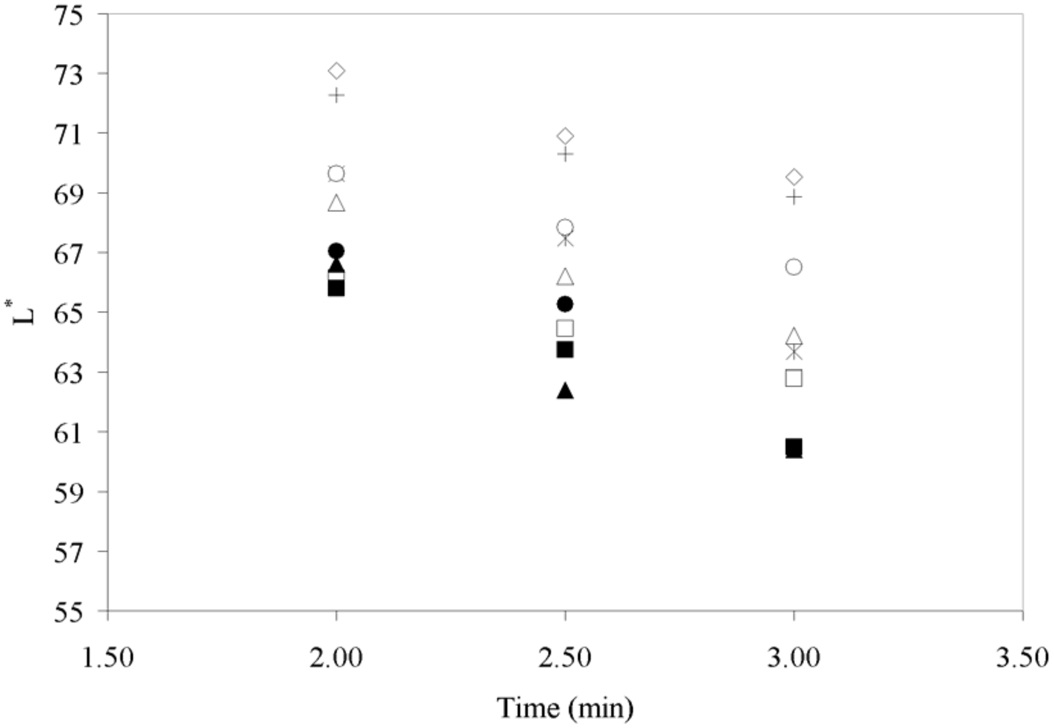

Figure 3.10 Variation of L^* value of the potatoes during frying at different microwave power levels and oil types. (■) 700W-Sunflower Oil; (▲) 700W- Corn Oil; (●), 700W-Nut Oil; (□) 550W- Sunflower Oil; (Δ), 550W-Corn Oil; (O), 550W-Nut Oil; (✱) 400W-Sunflower Oil; (◇) 400W-Corn Oil; (+) 400W-Nut Oil.

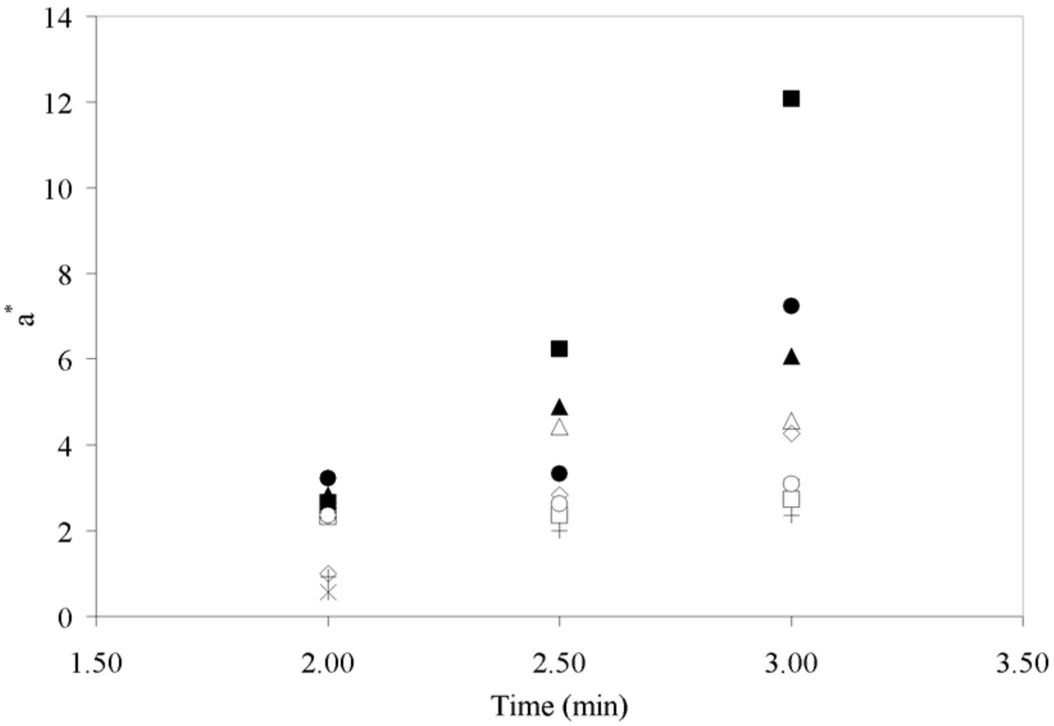

Figure 3.11 Variation of a^* value of the potatoes during frying at different microwave power levels and oil types. (■) 700W-Sunflower Oil; (▲) 700W- Corn Oil; (●), 700W-Nut Oil; (□) 550W- Sunflower Oil; (Δ), 550W-Corn Oil; (O), 550W-Nut Oil; (✱) 400W-Sunflower Oil; (◇) 400W-Corn Oil; (+) 400W-Nut Oil.

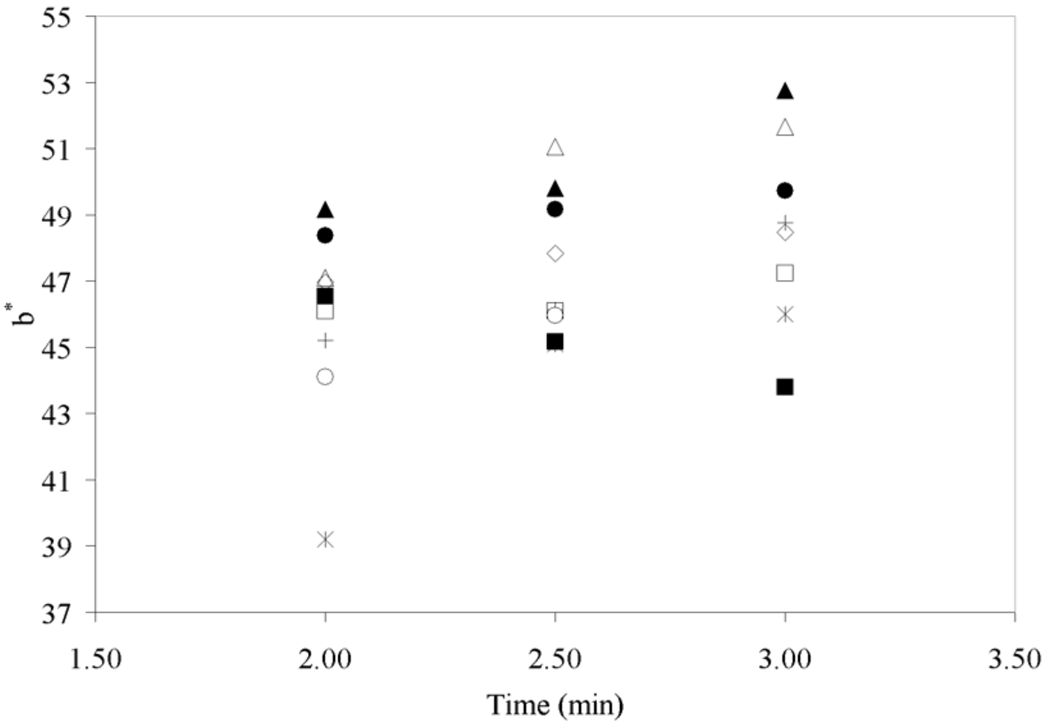

Figure 3.12 Variation of b^* value of the potatoes during frying at different microwave power levels and oil types. (■) 700W-Sunflower Oil; (▲) 700W- Corn Oil; (●), 700W-Nut Oil; (□) 550W- Sunflower Oil; (Δ), 550W-Corn Oil; (O), 550W-Nut Oil; (✱) 400W-Sunflower Oil; (◇) 400W-Corn Oil; (+) 400W-Nut Oil.

3.1.4 Texture

The effects of different microwave power levels and different oil types on the texture of fried potatoes were examined in terms of hardness. In Fig. 3.13, it can be seen that the hardness values increased with increasing frying time and microwave power level since as frying time and microwave power level increased, the moisture content decreased which resulted in harder products.

The hardness data were also far away from satisfying the assumption of normality. Therefore, transformation was performed to normalize the hardness results. Natural logarithm transformation satisfied the normality. In ANOVA and in optimization natural logarithm of the hardness values were used. The ANOVA results for hardness data are also given in Table 3.1. The microwave power level, frying time and oil type were all found to be significant for the hardness of the potatoes ($p<0.05$). Except the frying time-oil type interaction, all other interactions were found to be significant. Tukey-test showed that the levels of the three parameters were significantly different from each other. The potatoes fried in the sunflower oil were found to be the hardest ones, which were followed by the potatoes fried in nut and corn oil respectively.

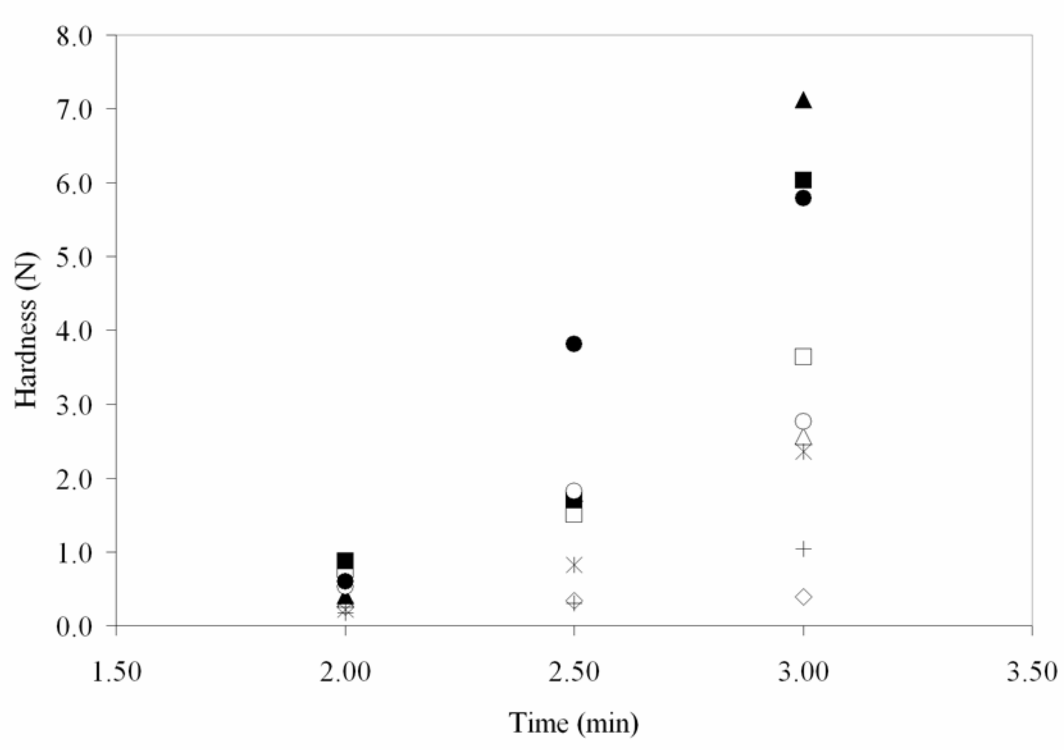

Figure 3.13 Variation of hardness of the potatoes during frying at different microwave power levels and oil types. (■) 700W-Sunflower Oil; (▲) 700W- Corn Oil; (●), 700W-Nut Oil; (□) 550W- Sunflower Oil; (Δ), 550W-Corn Oil; (O), 550W-Nut Oil; (✱) 400W-Sunflower Oil; (◇) 400W-Corn Oil; (+) 400W-Nut Oil.

3.1.5 Optimization

The overall evaluation criteria were calculated by the software depending on the specified quality characteristics and relative weights that are given in Table 3.2. The optimum condition was found to be the medium microwave power level 550 W, 2.50 minutes frying time and the sunflower oil.

Table 3.2 Evaluation Criteria Description

Criterion	Worst Reading	Best Reading	Quality Characteristic	Weighting (%)
Moisture Content (%)	1.811	3.391	N[a]	10
Oil Content (%)	0.355	0.586	B[b]	40
Color (ΔE)	55.29	49.075	N	30
Hardness (N)	0.0929	2.49262	N	20

[a] “The Nominal the best” quality characteristic

[b] “Bigger is the better” quality characteristic

The worst readings in Table 3.2 denote the worst results that are obtained in the experiments. Moisture content, color and hardness have “The Nominal the best” quality characteristics. The nominal values were based on the conventionally fried. For hardness, to provide normality natural logarithm of the hardness values were taken. The data for moisture and oil content was also transformed by using Box-Cox Transformation in order to satisfy normality and constant variance assumptions. For oil content, since consumers prefer less oil content products “smaller is the better” quality characteristics were chosen. However since Box-Cox transformation required a negative power, instead of “smaller is the better” “bigger is the better” quality characteristics was chosen. The relative weightings of the parameters were determined by the group consensus.

The ANOVA results for the overall evaluation criteria were given in Table 3.3. According to ANOVA results for the OEC oil type was the most significant factor followed by microwave power level- frying time interaction, frying time, respectively.

Table 3.3 Analysis of Variance for the Overall Evaluation Criteria

Source	d.f	Sum of Sqrs.(S)	Variance (V)	F Ratio	Pure Sum (S')	Percent (P%)
MW Power	2	562.949	281.474	3.612	407.135	3.443
Frying Time	2	1207.817	603.908	7.751	10052.03	8.898
MW Power x Frying Time	2	1781.136	19.97	18.84	37.81	19.52
MW Power x Frying Time	2	926.996	468.498	5.949	771.182	6.523
Oil Type	2	3441.097	1720.548	22.084	3285.283	27.79
MW Power x Oil Type	2	-91.083		Pooled		
MW Power x Oil Type	2	-181.158		Pooled		
Oil Type x Frying Time	2	830.015	415.007	5.326	674.201	5.703
Oil Type x Frying Time	2	-72.607		Pooled		
Other/Error	35	3071.591	74.916			33.895
Total	53	193.7				100

Table 3.4 shows the values for the quality parameters obtained in the optimum condition of microwave frying process and conventional deep-fat frying. It should be mentioned that the microwave-fried potatoes had lower oil content than the conventionally fried ones. At the optimum condition microwave fried potatoes had similar ΔE and hardness values with conventionally fried ones.

Table 3.4 Comparison of the quality of potatoes fried in optimum condition for microwave frying (550 W, 2.5 min, sunflower oil) and conventional deep-fat frying in sunflower oil

Quality Parameters	Microwave Frying	Conventional Deep-Fat Frying
Moisture Content (%) (db)	42.04	67.44
Oil Content (%) (db)	27.4	41.28
ΔE	48.63	49.075
Hardness (N)	1.5589	1.6366

3.2 Effects of microwave frying on the quality parameters of osmotically dehydrated potato slices

3.2.1 Moisture Content

The initial moisture content of potatoes was in the range 80-82% (wet basis). The osmotic dehydration process decreased the initial moisture contents of potatoes. The moisture contents of the potatoes and the water activities of the potatoes after osmotic dehydration are given in Figure 3.14 and 3.15 respectively. It can be seen that the decrease in moisture content was high in the first 15 minutes whereas it was quite low after 30 minutes. The water activity of the osmotically dehydrated potatoes also confirms that trend. (Fig. 3.15)

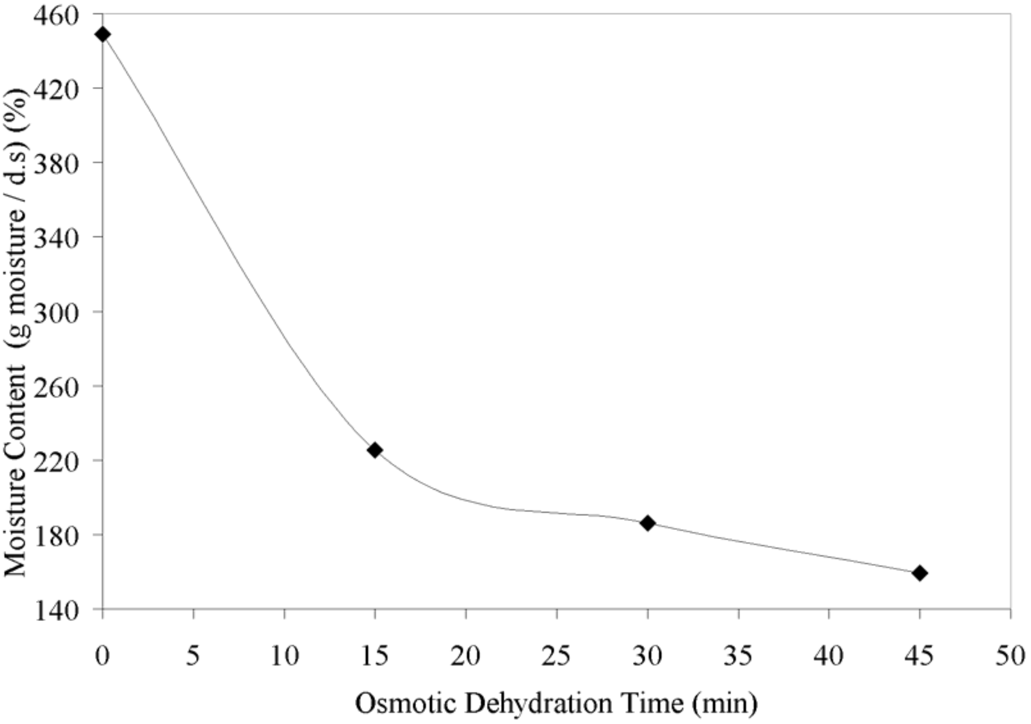

Figure 3.14 Effect of osmotic dehydration on moisture content (db) of raw potatoes

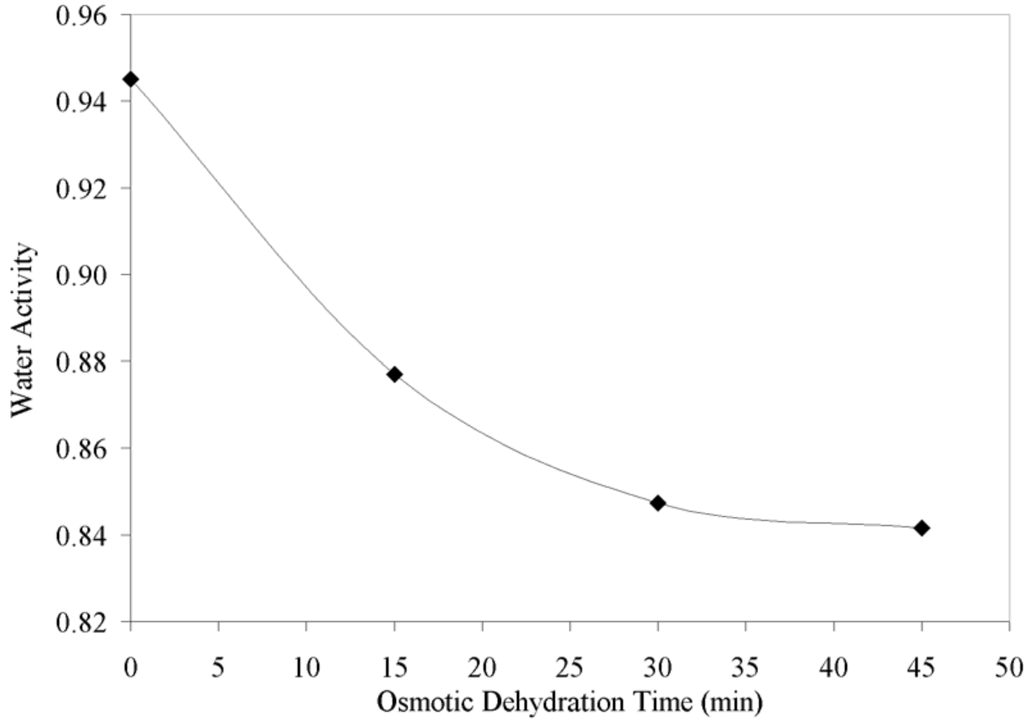

Figure 3.15 Effect of osmotic dehydration on water activity of raw potatoes

It was observed that moisture was lost during frying and increasing the power level above 550 W did not increase moisture loss significantly for all dehydration times (Figure 3.16-3.18).

According to Tukey test results (Table C.6), 400 W of microwave power level was found to be significantly different from 550 W and 700 W whereas no significant difference was detected between 550 W and 700 W microwave power levels in terms of moisture content. For frying time and osmotic dehydration time, all the levels were found to be significantly different from each other.

The experimental data for this part of the study can be found in Appendix in Table C.1.

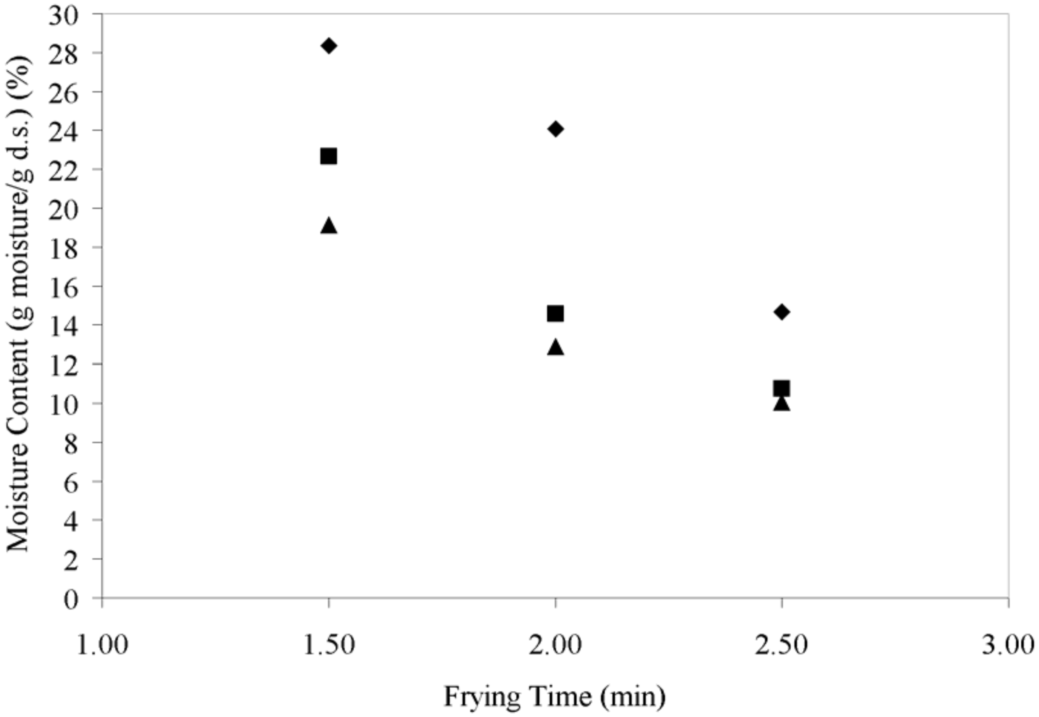

Figure 3.16 Variation of moisture content of osmotically dehydrated potatoes for 15 minutes during frying at different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

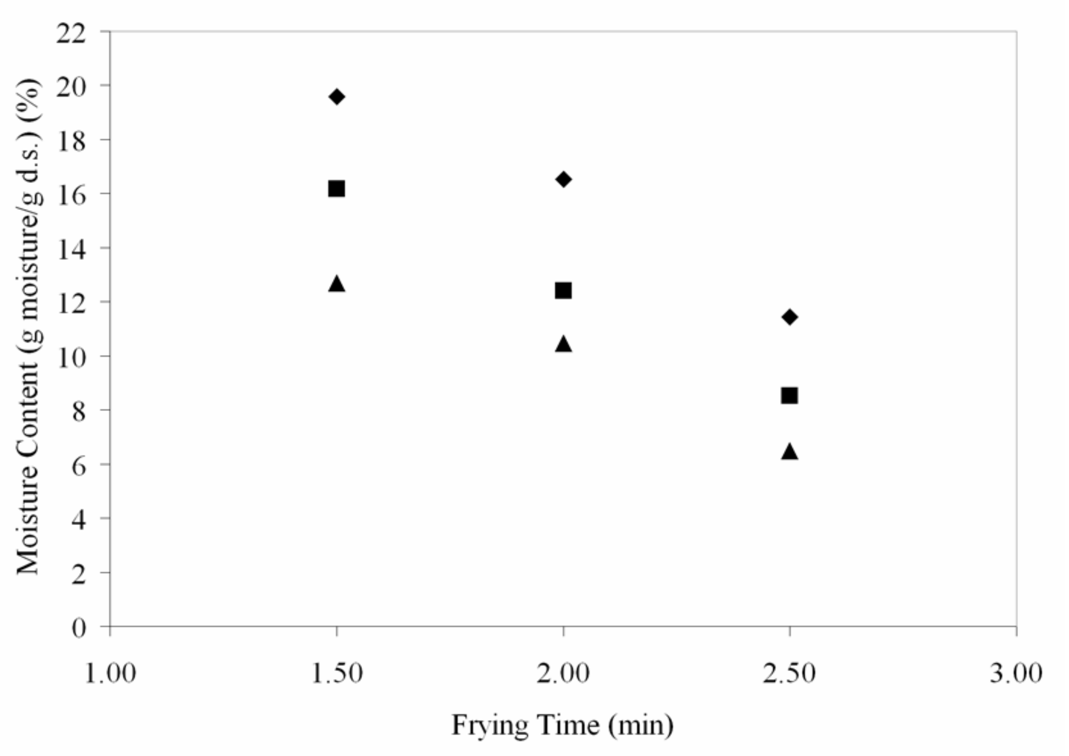

Figure 3.17 Variation of moisture content of osmotically dehydrated potatoes for 30 minutes during frying at different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

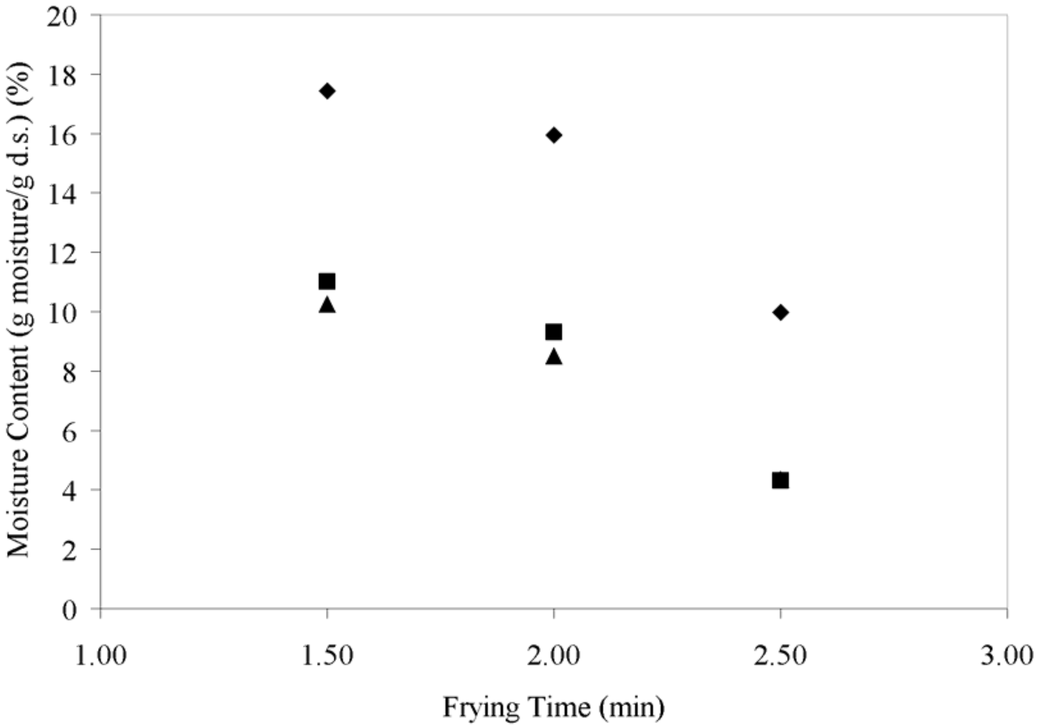

Figure 3.18 Variation of moisture content of osmotically dehydrated potatoes for 45 minutes during frying at different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

When the effect of dehydration time was examined during frying at 400 W microwave power level it was seen that as dehydration time and frying time increased moisture loss increased as well (Figure 3.19). The rate of moisture loss was higher when the osmotic dehydration time was lower (15 min). This was an expected result in the sense that at lower dehydration times the initial moisture content was higher resulting in higher driving force during frying. According to Tukey test, there was no significant difference between osmotic dehydration time for 30 min and 45 min with respect to their effects on moisture content of fried potatoes at 400 W (Fig. 3.19) (Table C.10). Similar trend was observed during frying at higher microwave power levels (Fig 3.20 and 3.21).

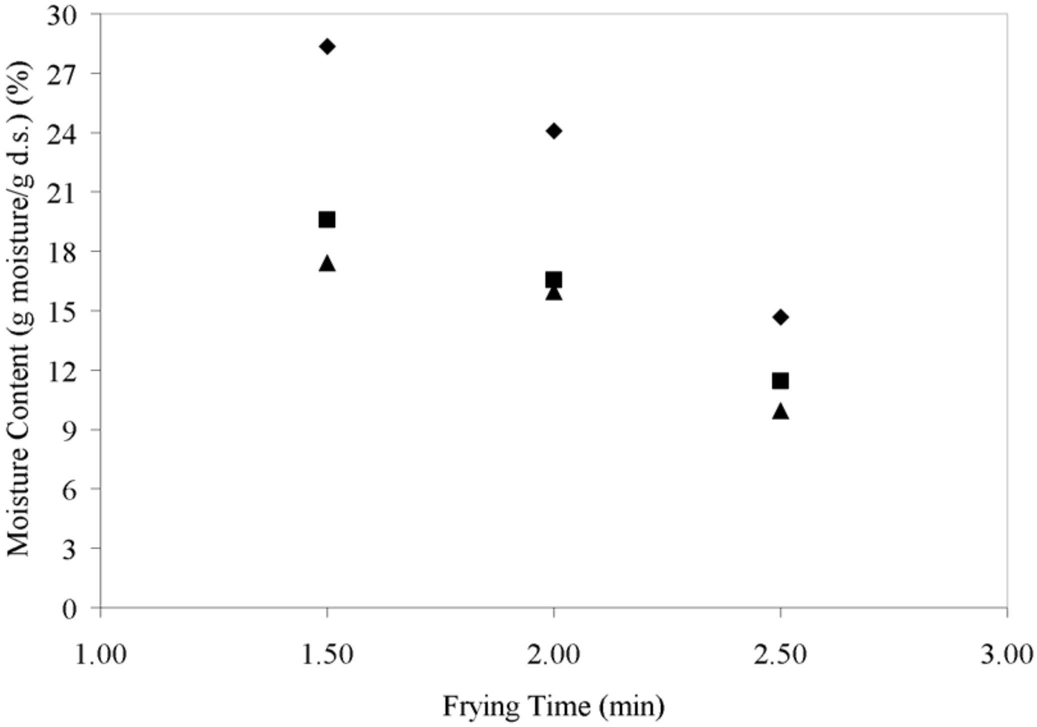

Figure 3.19 Variation of moisture content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 400 W: (♦) 15 min; (■) 30 min; (▲) 45 min.

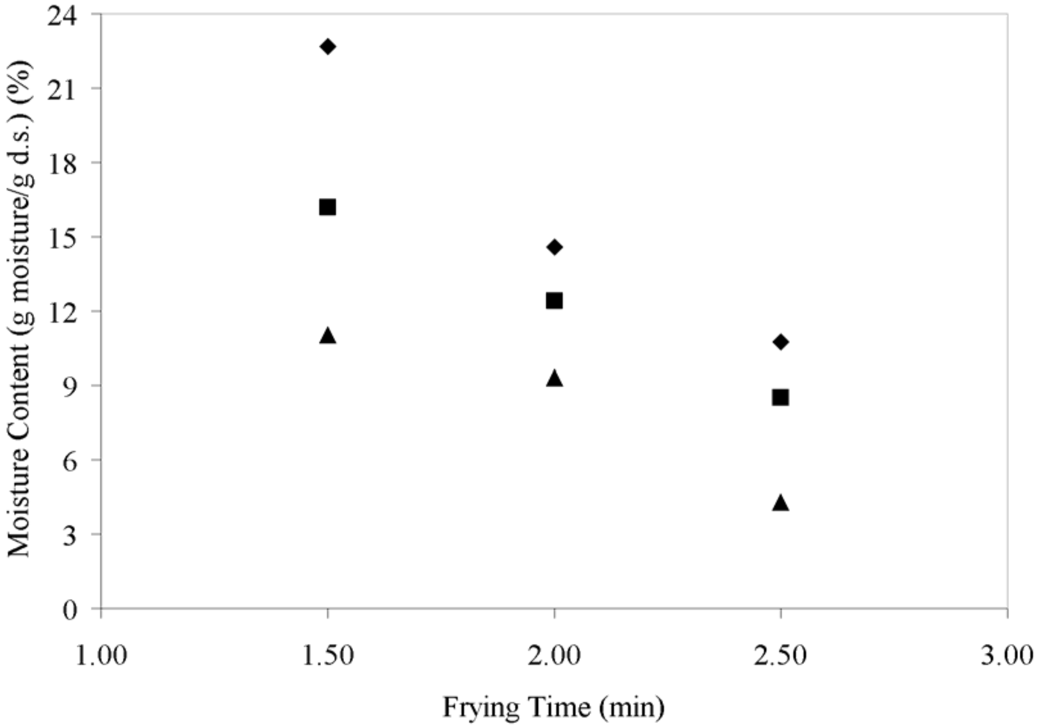

Figure 3.20 Variation of moisture content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 550 W: (♦) 15 min; (■) 30 min; (▲) 45 min.

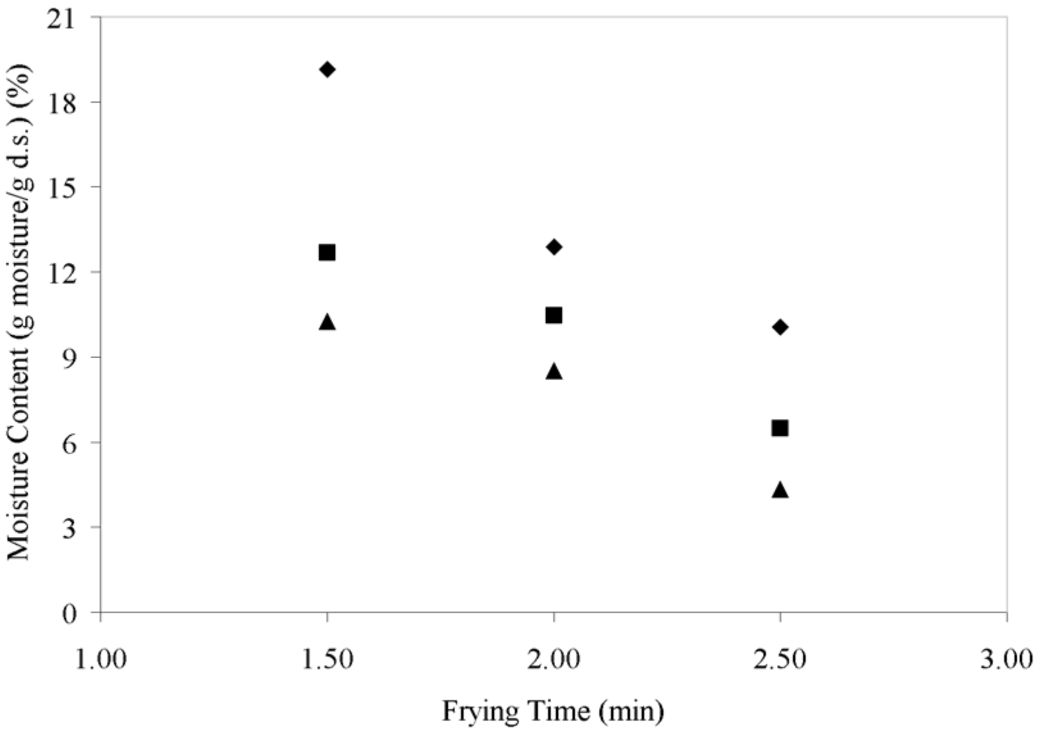

Figure 3.21 Variation of moisture content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 700 W: (♦) 15 min; (■) 30 min; (▲) 45 min.

When the ANOVA results for moisture content was examined, it was found that microwave power, frying time and osmotic dehydration time were all significant on moisture content ($p<0.05$) (Table 3.5). Except frying time-osmotic dehydration time interaction all two-way and the three-way interactions were found to be insignificant ($p>0.05$). The detailed ANOVA table for moisture content is available in Appendix Table C.2.

Table 3.5 ANOVA Table for microwave fried osmotically dehydrated potatoes

Source	d.f.	Moisture Content % (db)	Oil Content % (db)	Color (ΔE)	Hardness (N)
		p	p	p	p
MW Power	2	0.0000	0.0000	0.0000	0.0000
Frying Time	2	0.0000	0.0000	0.0010	0.0000
Osmotic Dehydration (OD) Time	2	0.0000	0.0000	0.0000	0.0000
MW Power x Frying Time	4	0.6950	0.2250	0.0000	0.0300
MW Power x OD Time	4	0.6670	0.9400	0.0140	0.3100
Frying Time x OD Time	4	0.0260	0.8350	0.4110	0.7700
MW Power x Frying Time x OD Time	8	0.9990	0.8770	0.4120	0.9230
Error	27				
Total	53				

The moisture content of potatoes fried in the conventional deep fat fryer for 4.0 minutes were 20.75 %, 16.37 %, 12.82 % (db) when soaked in the salt solution for 15, 30, 45 minutes prior to frying, respectively. The moisture content of potatoes fried in microwave oven even at low power level (400 W) for 2.5 min when soaked in the salt solution for 15, 30, 45 minutes were lower than the conventionally fried ones (14.67 %, 11.43 %, and 9.97 % db for dehydration times of 15, 30 and 45 minutes, respectively). The resulting difference between conventional deep-fat frying and microwave frying was expected since microwaves increased moisture loss significantly.

In order to understand the effect of salt which diffused into the potatoes during dehydration, initial moisture content of potatoes were reduced to the same level as osmotic dehydration by conventional drying. Frying was performed at 550 W power level for 1.5 minutes. The final moisture content of the potatoes that were equivalent in terms of their initial moisture content to the ones that were held for 30 minutes in salt solution was 29.56 % (db). On the other hand, the moisture contents of the microwave fried (550 W for 1.5 min) potatoes that were osmotically dehydrated for 30 min prior to frying was 16.18 % (db). The lower moisture content of the microwave fried potatoes after osmotic dehydration was due to penetration of salt into the product which caused an increase in dielectric loss factor. Microwave absorptivity of a material depends on dielectric loss factor and therefore, the increase in loss factor results in higher temperature of the product. In frying, the loss factor does not decrease with decreasing moisture content but increases due to the presence of salt. Foods with added salts are known to show continuous increase in dielectric constant and loss factor with respect to temperature (Calay, Newborough, Probert and Calay, 1995). The increase in dielectric loss factor causes the product to be heated more. As a result, moisture loss increases. This result was also confirmed by the temperature profiles of the potatoes during frying (Figure 3.22). It is obvious from the figure that the temperature of the fried potatoes that were subjected to osmotic dehydration was higher during frying than the conventionally dried microwave fried potatoes and microwave fried potatoes that were not osmotically dehydrated.

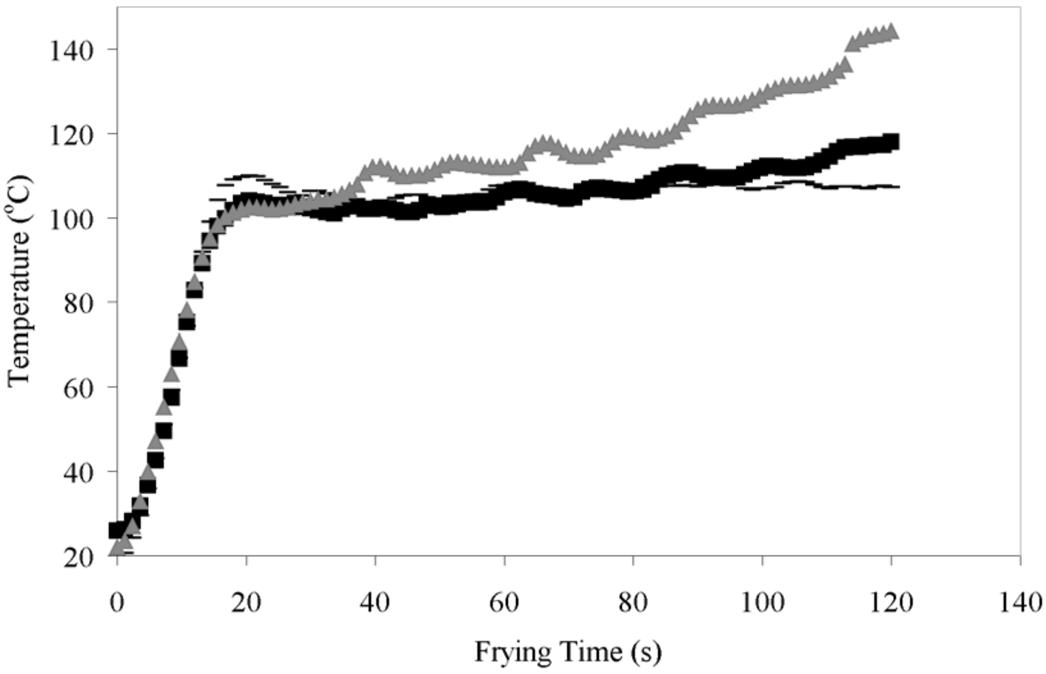

Figure 3.22 Comparison of center temperature of potatoes during different frying methods: (-) Conventionally dried and microwave fried potatoes; (■) Microwave fried potatoes without osmotic dehydration; (▲) Osmotically dehydrated microwave fried potatoes.

3.2.2 Oil Content

Oil content is one of the most important quality attributes of a deep-fat fried product. Osmotic dehydration is used as a pretreatment before frying to produce low-fat fried potatoes.

Figure 3.23, shows how oil content changed with respect to frying time for different microwave power levels when potatoes were held in salt solution for 15 min prior to frying. As microwave power and frying time increased oil content increased. This result is consistent with the fact that high moisture loss causes high oil uptake since as microwave power and frying time increased moisture loss increased (Fig. 3.16 and 3.23). The difference between microwave power levels of 550 W and 700 W was not very significant. Similar results were obtained when the osmotic dehydration times were higher (Fig. 3.24 and 3.25).

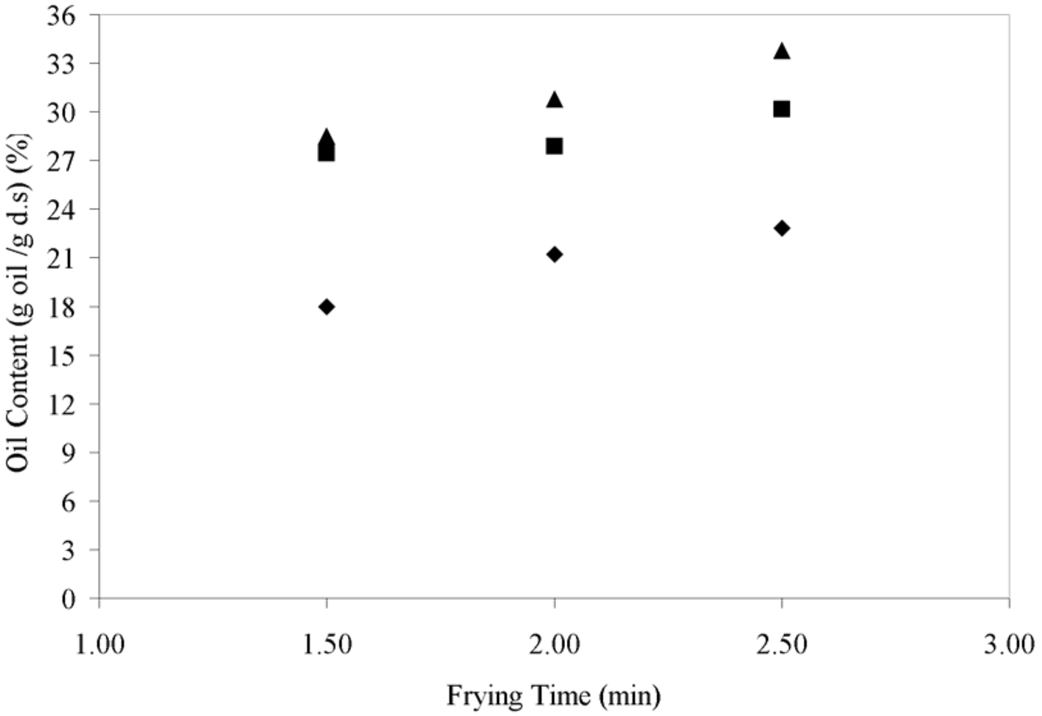

Figure 3.23 Variation of oil content of osmotically dehydrated potatoes for 15 minutes during frying at different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

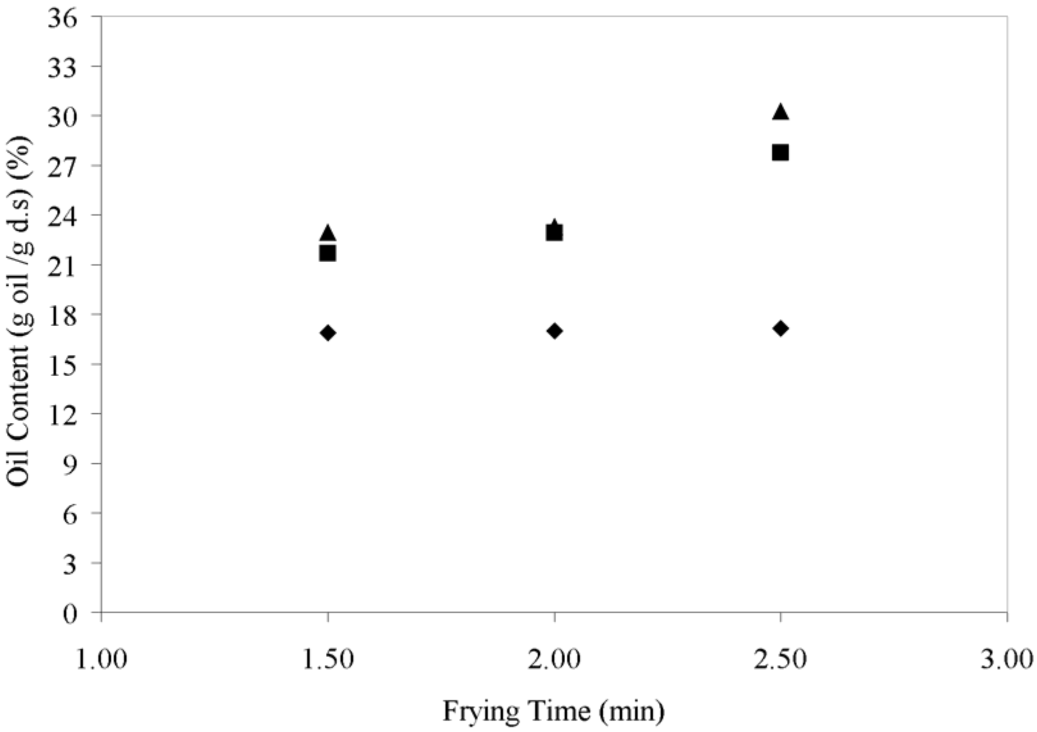

Figure 3.24 Variation of oil content of osmotically dehydrated potatoes for 30 minutes during frying at different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

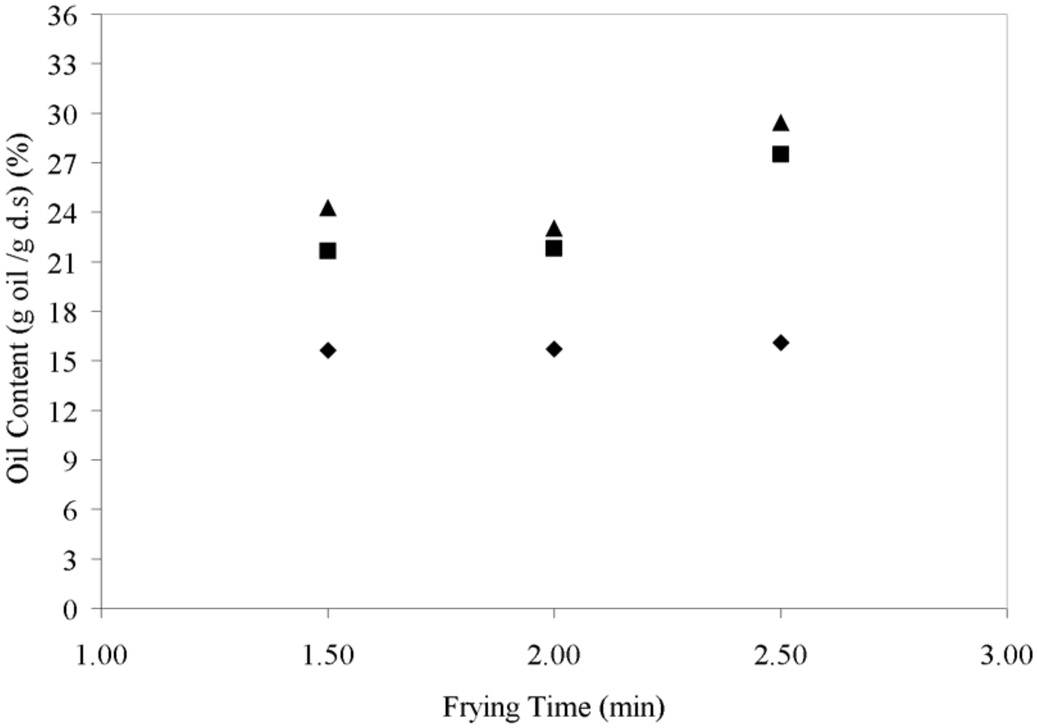

Figure 3.25 Variation of oil content of osmotically dehydrated potatoes for 45 minutes during frying at different microwave power levels: (♦) 400 W; (■) 550 W; (▲) 700 W.

When the microwave power was kept constant and the relationship between frying time and osmotic dehydration time was examined it was seen that as dehydration time increased oil content decreased (Fig. 3.26-3.28). The increase in osmotic dehydration time reduced the moisture content of potatoes which caused reduction in moisture loss and consequently oil uptake during frying. There was no significant difference between osmotic dehydration time of 30 min and 45 min in affecting oil content. When the Tukey test results (Table C.7) are examined it was seen that 440 W was significantly different from 550W and 700W whereas there was not a significant difference between 550W and 700W in terms of oil content ($p>0.05$). For frying time, 1.5 and 2 minutes were found to statistically insignificant ($p>0.05$). However, 2.5 minutes was found to be significantly different from the two other frying time ($p<0.05$). For osmotic dehydration time 15 minutes was found to be statistically different from 30 and 45 minutes whereas no difference was found between 30 and 45 minutes ($p>0.05$)

The lowest oil content (15.65 % db) was observed in the potatoes that were fried at 400W microwave power level for 1.5 minutes and dehydrated for 45 minutes. Oil content of these potatoes were less than the oil content of conventionally fried potatoes that were osmotically dehydrated for 15, 30, 45 minutes (27.83 %, 17.79 %, 17.95 % (db) respectively). Oil content data of the fried potatoes is available in Appendix Table C.11. For other microwave power levels and dehydration times the oil content of osmotically dehydrated microwave fried potatoes was not found to be smaller than the osmotically dehydrated conventionally fried ones as seen in Table C.11. However, the oil content of the osmotically dehydrated microwave fried potatoes was smaller when compared with conventionally fried potatoes that were not treated osmotically (41.28 % db). This result supports the use of osmotic dehydration as a pre treatment before frying to reduce oil uptake. Another interesting result was the high oil content of the microwave fried potatoes that were not osmotically dehydrated but dried conventionally as a pre treatment (Table C.11). The high oil content of these potatoes may be explained due to structural changes that take place during conventional drying which enables easy uptake of oil. If the potatoes were dehydrated partially in conventional oven, highly porous structure was obtained which were filled with oil during frying. When they were osmotically dried there was less space for oil to enter since the pores were partially filled with salt. In accordance with this result Krokida, Oreopoulou, Maroulis and Marinos-Kouris (2001b) found that pre-drying decreased the oil and moisture contents of french fries whereas increased the porosity. The structural changes that occurred in the fried potatoes can be seen in the pictures that are available in Appendix (Fig. D.4).

However the oil content of the pre-dried microwave fried potatoes were still lower than the ones that were not pre-treated.

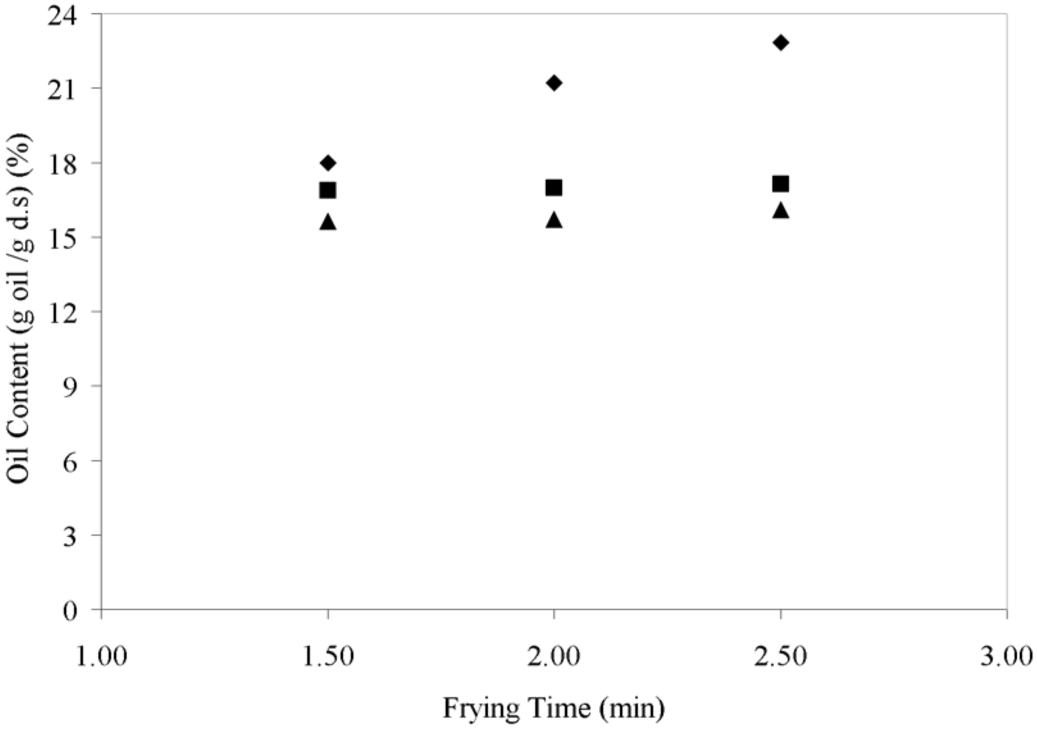

Figure 3.26 Variation of oil content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 400 W: (♦) 15 min; (■) 30 min; (▲) 45 min.

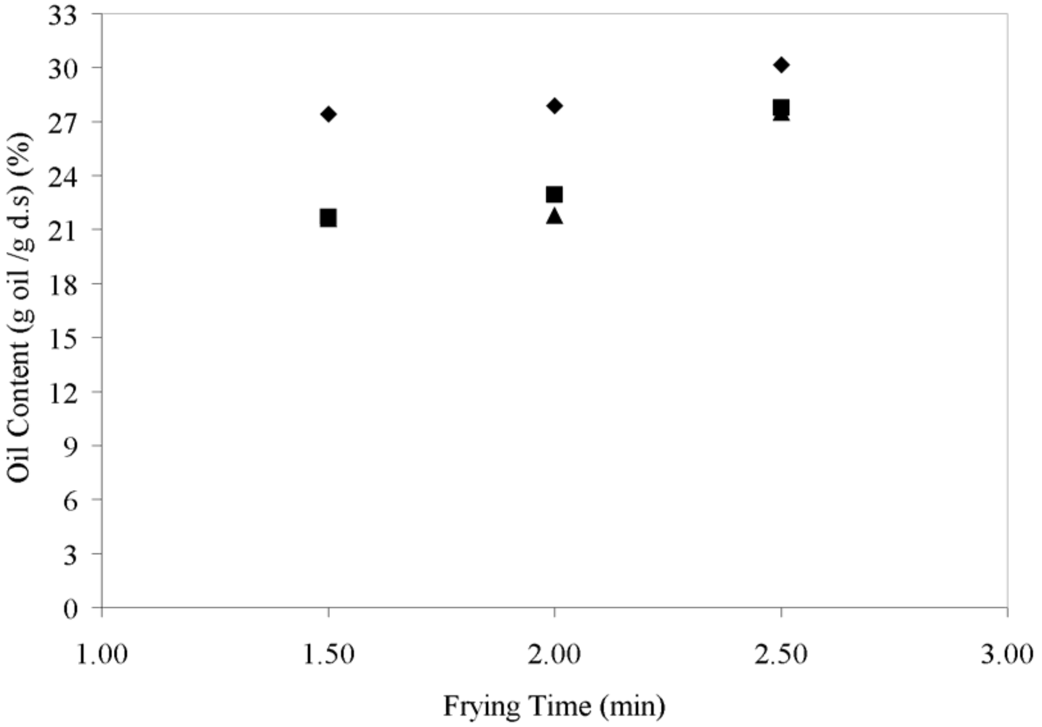

Figure 3.27 Variation of oil content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 550 W: (♦) 15 min; (■) 30 min; (▲) 45 min.

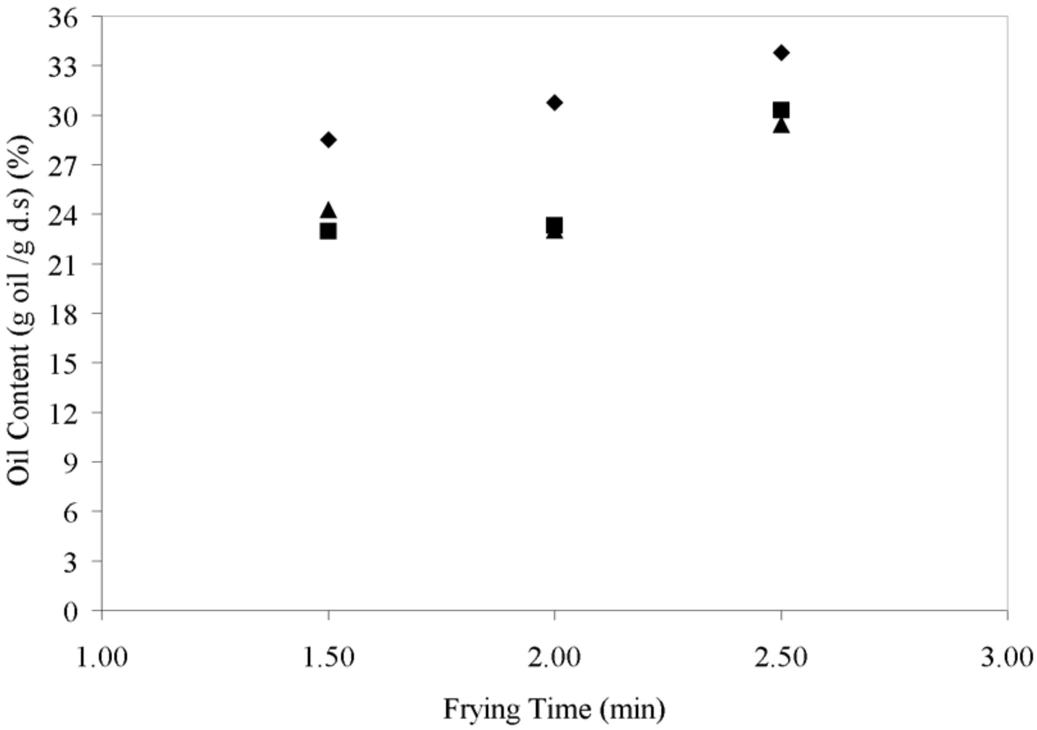

Figure 3.28 Variation of oil content of osmotically dehydrated potatoes for different osmotic dehydration times during frying at 700 W: (♦) 15 min; (■) 30 min; (▲) 45 min.

When the ANOVA results for oil content were examined (Table 3.5), it was seen that microwave power level, frying time and osmotic dehydration time were all significant on affecting the oil content ($p<0.05$). However, all two-way interactions and the three-way interaction were found to be insignificant ($p>0.05$). The detailed ANOVA table is available in Appendix (Table C.3).

3.2.3 Color

Krokida, Oreopoulu, Maroulis and Marinos-Kauris (2001c) found out that the lightness of potato strips increased during early stages of frying while it remained almost constant afterwards. Moreover, they stated that as temperature of the frying medium increased lightness decreased. Lightness of potato strips increased during frying, in the case of 400 W microwave power level which may correspond to the initial stages of frying compared to other power levels as Krokida Oreopoulou, Maroulis and Marinos-Kauris (2001c) stated (Fig. 3.29) . For microwave power levels of 550 W and 700 W, as frying time increased lightness decreased due to increase in temperature (Figure 3.29). A significant difference in L^* value could not be detected between the osmotically treated microwave and conventionally fried potatoes (Table C.12).

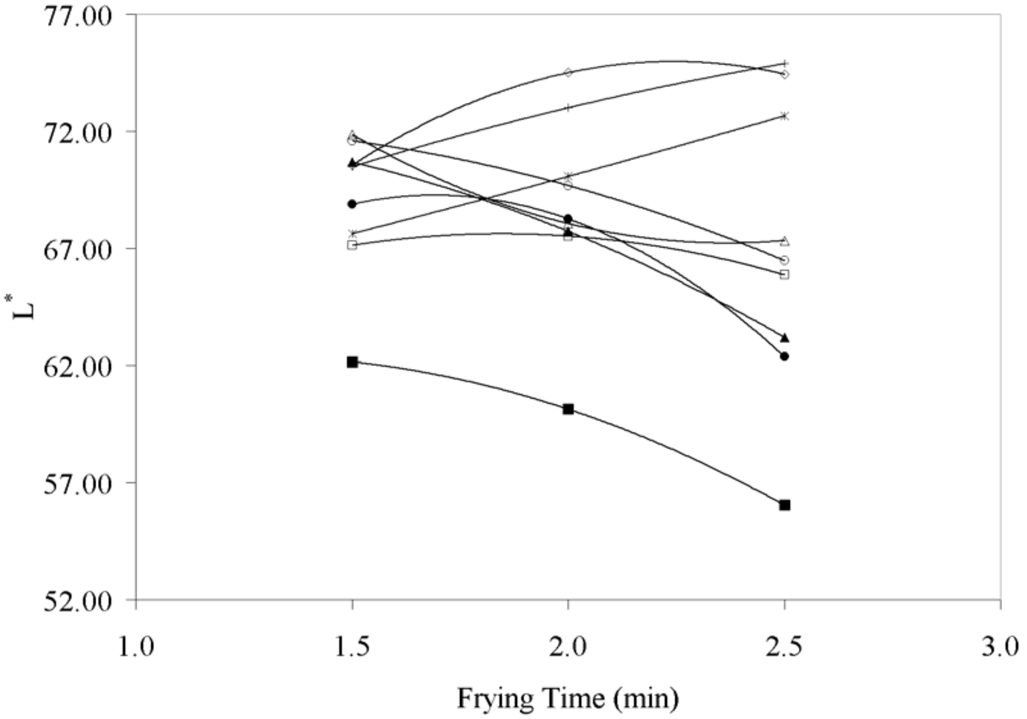

Figure 3.29 Variation of L^* value of the potatoes during frying at different microwave power levels and osmotic dehydration times: (■) 700W-15 min; (▲) 700W- 30 min; (●), 700W-45 min; (☐) 550W- 15 min; (Δ), 550W-30 min; (O), 550W-45 min; (✱) 400W-15 min; (◇) 400W-30 min; (+) 400W-45 min

In microwave frying of osmotically dehydrated potatoes it was found out that as osmotic dehydration time increased lightness increased. (Figure 3.30).This may be because of decreasing rate of Maillard reactions by reducing the moisture content of the sample. This may also be explained by the salt which entered into the potato during dehydration and diffused to surface after frying that resulted in higher L^* values. The L^* values of microwave fried potatoes that were not treated osmotically but dried in conventional oven to the same moisture level were very low compared to L^* values of the microwave fried potatoes that were osmotically dehydrated and fried at the same microwave power level (Table C.12). When potatoes were dried in a conventional oven prior to frying browning reaction starts during drying. However, this is not the case in osmotic dehydration. Krokida Oreopoulou, Maroulis and Marinos-Kauris also (2001c) observed a negative effect on color development with pre-drying.

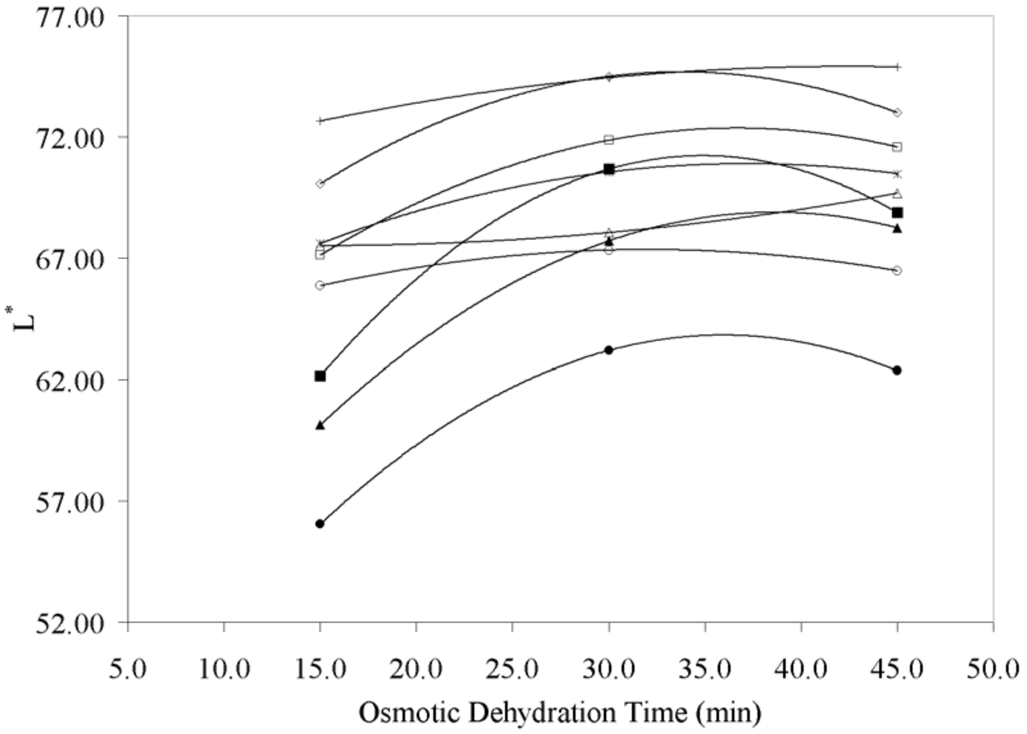

Figure 3.30 Variation of L^* value of the potatoes during frying at different microwave power levels and frying times. (■) 700W-1.5 min; (▲) 700W- 2.0 min; (●), 700W-2.5 min; (□) 550W- 1.5 min; (Δ), 550W-2.0 min; (O), 550W-2.5 min; (✱) 400W-1.5 min; (◇) 400W-2.0 min; (+) 400W-2.5 min

Another parameter that is considered in color analysis is the a^* value. In general an increase in a^* value is not desired since it results in a red potato. The a^* parameter of the potatoes increases significantly due to browning reactions. As the temperature of the frying increases a value increases for the same frying time which is negative for the color of fried products (Krokida, Oreopoulu, Maroulis and Marinos-Kauris 2001c). In the microwave frying, as microwave power level and frying time increased, a^* value of potatoes increased (Table C.12). However, a relationship between osmotic dehydration time and a^* value could not be detected.

The total color difference (ΔE) of potatoes increased as microwave power level and frying time increased for power levels of 550 W and 700W (Fig. 3.31). As microwave power level increases the temperature of the frying oil increases, which in turn increases the rate of non-enzymatic browning reactions. Consequently the color of potatoes becomes darker and ΔE increases. The situation is different for the power level of 400 W. As frying time increased ΔE value decreased which is due to increase in L^* value at this power level. ΔE values of the microwave fried potatoes that were not osmotically dehydrated were higher than that of osmotically dehydrated ones when the power level is at 400 W and 550 W (Appendix C.12). ΔE values of the conventionally dried and microwave fried potatoes were found to be greater than the osmotically dehydrated and microwave fried potatoes which may be explained by the browning reactions that also take place during conventional drying in the 105 ^{o}C oven (Appendix C.12). All the levels of the microwave power were significantly different from each other as a result of the Tukey test (Appendix C.8) ($p<0.05$). For frying time, there was no significant difference between 1.5 minute and 2.0 minutes ($p>0.05$) whereas there was significant difference between 2.5 minutes and the other levels ($p<0.05$). In osmotic dehydration time, no significant difference was found between 30 and 45 minutes whereas 15 minutes differed significantly.

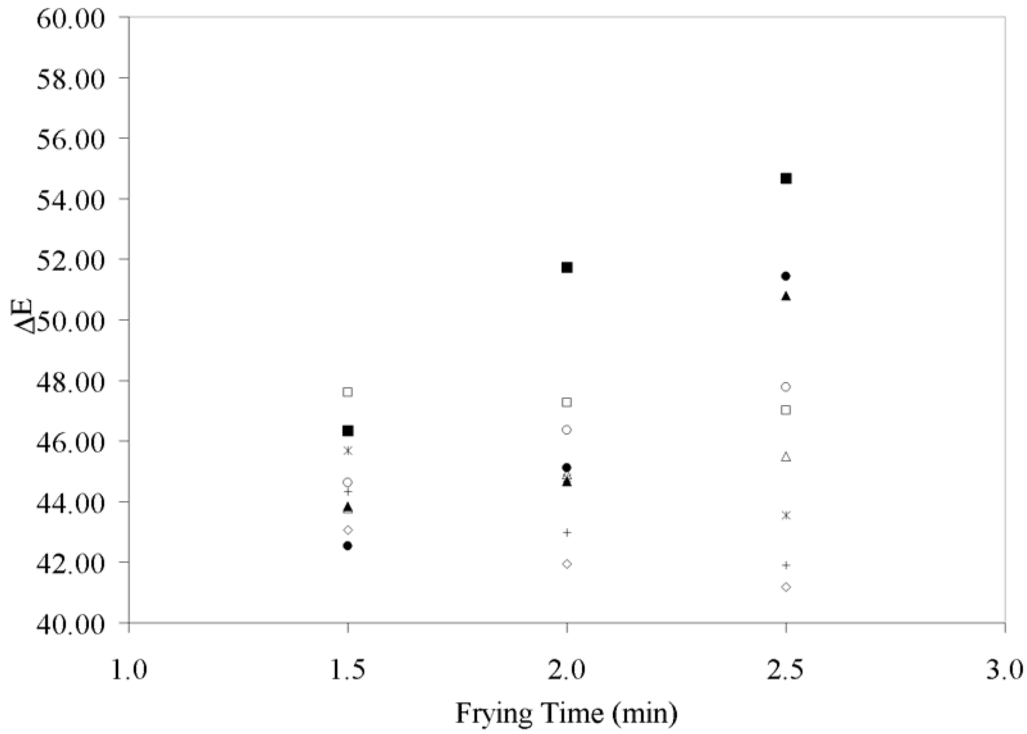

Figure 3.31 Variation of ΔE value of the potatoes during frying at different microwave power levels and osmotic dehydration times. (■) 700W-15 min; (▲) 700W- 30 min; (●), 700W-45 min; (□) 550W- 15 min; (Δ), 550W-30 min; (O), 550W-45 min; (✱) 400W-15 min; (◇) 400W-30 min; (+) 400W-45 min

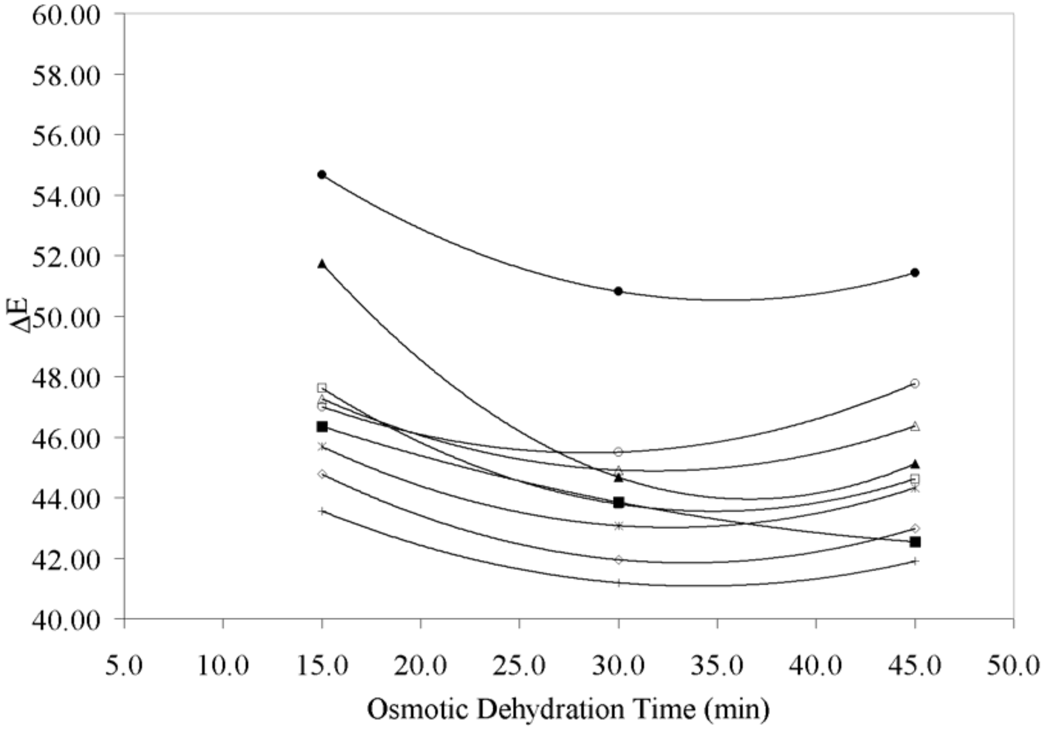

Figure 3.32 Variation of ΔE value of the potatoes during frying at different microwave power levels and frying times. (■) 700W-1.5 min; (▲) 700W- 2.0 min; (●), 700W-2.5 min; (□) 550W- 1.5 min; (Δ), 550W-2.0 min; (O), 550W-2.5 min; (✱) 400W-1.5 min; (◇) 400W-2.0 min; (+) 400W-2.5 min

Osmotic dehydration time was not effective on ΔE value of the fried potato, after 30 min (Fig. 3.32). This can also be seen according to Tukey results (Table C.8). The pictures of the dehydrated potatoes fried under different conditions are available in Appendix D.1-D.3.

According to ANOVA results for the ΔE values (Table 3.5), it was seen that microwave power level, frying time and osmotic dehydration time were all significant in affecting total color difference ($p<0.05$). Among the interactions, except the frying time-osmotic dehydration time and the three way interaction, the other two way interactions were found to be significant ($p<0.05$). The detailed ANOVA table is available in Table C.4.

3.2.4 Texture

The effects of different microwave power levels and different osmotic dehydration times on the texture of fried potatoes were examined in terms of hardness. In Fig. 3.33, it can be seen that the hardness values increased with increasing frying time and microwave power level since as frying time and microwave power level increased, the moisture content decreased which resulted in harder products.

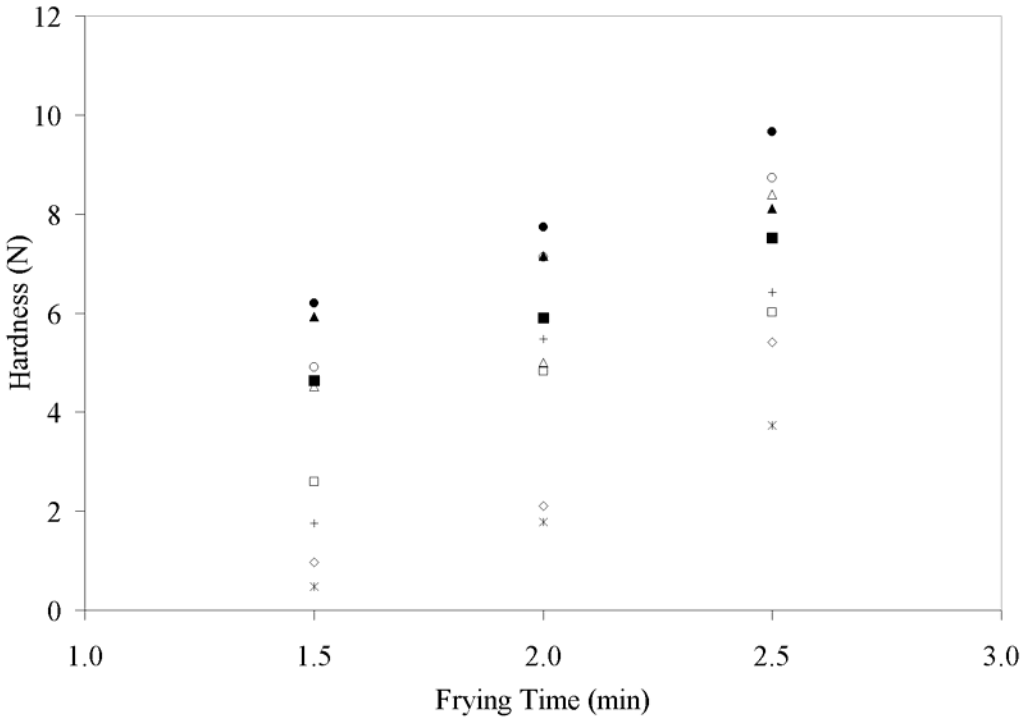

Figure 3.33 Variation of hardness of the potatoes during frying at different microwave power levels and osmotic dehydration times. (■) 700W-15 min; (▲) 700W- 30 min; (●), 700W-45 min; (□) 550W- 15 min; (Δ), 550W-30 min; (O), 550W-45 min; (✱) 400W-15 min; (◇) 400W-30 min; (+) 400W-45 min

When the relationship between osmotic dehydration time and hardness was examined it was found out that as dehydration time increased hardness increased (Fig. 3.34). The hardness of the conventionally fried potatoes that were osmotically dehydrated was also greater than the ones that were not osmotically dehydrated (Table C.13). Bunger, Moyano and Rioseco (2003) also found out that soaking in NaCl solution before frying had increased hardness values for french fries. Bunger, Moyano and Rioseco (2003) stated that increased soaking time improved the sensory textural quality, probably due to higher diffusion of the NaCl into the tissue that resulted in an increase in tissue resistance.

The effect of osmotic dehydration on texture becomes obvious when the hardness values of the potatoes that were not subjected to osmotic dehydration were examined. As can be seen in Table C.13, the hardness values were lower for the microwave fried potatoes that were not subjected to osmotic dehydration than the ones that are osmotically dehydrated. Presence of salt increases heating rate and moisture loss which leads to harder products. The hardness of the potatoes that were dried conventionally was comparably smaller than the hardness values of the potatoes that were osmotically dehydrated. This can be explained by the interaction of salt with microwaves.

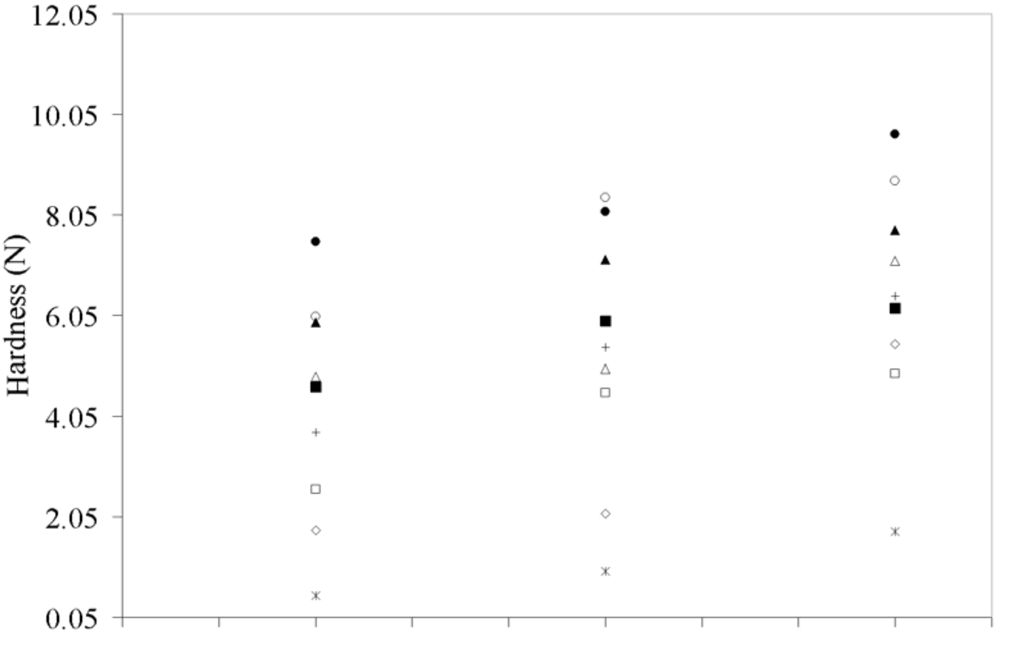

Figure 3.34 Variation of hardness of the potatoes during frying at different microwave power levels and frying times. (■) 700W-1.5 min; (▲) 700W- 2.0 min; (●), 700W-2.5 min; (□) 550W- 1.5 min; (Δ), 550W-2.0 min; (O), 550W-2.5 min; (✱) 400W-1.5 min; (◇) 400W-2.0 min; (+) 400W-2.5 min

When ANOVA was performed it was seen that the residuals for the hardness data were far away from satisfying the assumption of constant variance which is a required condition for ANOVA to be meaningful. Therefore, transformation was performed to satisfy the constant variance assumption results. The λ value for the hardness data was found as 0.225 by using MINITAB 14. The transformed form of the hardness data satisfied the constant variance assumption. In ANOVA and further optimization studies $Hardness^{0.225}$ values were used. As a result of the ANOVA (Table 3.5), microwave power level, frying time and osmotic dehydration time were all found to be significant for the hardness of the potatoes ($p<0.05$). Except microwave power-frying time interaction, all other interactions were found to be insignificant ($p>0.05$). The detailed ANOVA table is available in Table C.5. Tukey-test for the parameters (Table C.9) showed that all levels of the frying time and osmotic dehydration time were significantly different from each other. For microwave power level no significant difference was found between 550 W and 700 W whereas 400 W was found to be significantly different.

3.2.5 Optimization

Optimization was performed by using two different methods in this part of the study: Taguchi Technique and Response Surface Methodology.

3.2.5.1 Taguchi Technique

The overall evaluation criteria were calculated by the software depending on the specified quality characteristics and relative weights that are given in Table 3.6. The relative weightings of the parameters are determined by the group consensus.

Table 3.6 Evaluation Criteria Description

Criterion	Worst Reading	Best Reading	Quality Characteristic	Weighting (%)
Moisture Content (%)	2.94	28.82	B[a]	10
Oil Content (%)	41.28	14.29	S[b]	40
Color (ΔE)	60	49.075	N[c]	30
Hardness$^{0.225}$ (N) (Box-Cox Transformed)	1.713	1.117	N	20

[a] "The Bigger is the better" quality characteristic

[b] "Smaller is the better" quality characteristic

[c] "Nominal is the best" quality characteristic

For hardness and color, the best readings were taken as the hardness and ΔE values of the conventionally fried potatoes that were not treated osmotically since they are considered as 'acceptable'. For the worst reading, the values for darkest and the hardest potatoes were taken.

For moisture content the maximum moisture content among the available data was taken since moisture contents of the conventionally fried potatoes that were not treated osmotically was 67.44 % (db). Since such a huge number was not available in the data, the largest of the available was taken as the best reading. For the worst reading the lowest moisture content was taken.

For oil content the minimum oil content among the available data was taken since oil contents of the conventionally fried potatoes that were not treated osmotically was 41.28 % (db). As the worst value 41.28 % (db) was taken.

As a result of optimization the optimum condition was found to be the power level of 400 W, 1.50 minutes frying time and 30 minutes osmotic dehydration time.

The ANOVA results for the overall evaluation criteria (OEC) are given in Table 3.7. According to ANOVA results for the OEC microwave power is the most significant factor followed by frying time. Osmotic dehydration time was found to be insignificant on OEC.

Table 3.7 ANOVA Table for the Overall Evaluation Criteria

Source	d.f	Sum of Sqrs.(S)	Variance (V)	F Ratio	Pure Sum (S')	Percent (P%)
MW Power	2	6036.62	3018.31	70.561	5951.069	47.611
Frying Time	2	4071.286	2035.643	47.588	3985.735	31.887
MW Power x Frying Time	2	69.193	34.596	0.808	0	0
MW Power x Frying Time	2	45.959	22.979	0.537	0	0
Osmotic Dehydration Time	2	62.43	31.215	0.729	0	0
MW Power x OD Time	2	125.517	62.758	1.467	39.965	0.319
MW Power x OD Time	2	290.786	145.393	3.398	205.234	1.641
OD Time x Frying Time	2	136.188	68.094	1.591	50.637	0.405
OD Time x Frying Time	2	164.054	82.027	1.917	78.503	0.628
Other/Error	35	1497.147	42.775			17.509
Total	53	12499.185				100

3.2.5.2 Response Surface Methodology

In this study, due to number of factors and their levels, RSM was performed by using a Box-Behnken design.

The first analysis step in RSM is to fit appropriate regression equations for the responses. After the regression models are built by, tests were performed to find out whether the regression models satisfy the assumptions. It was found out that except the hardness data all responses satisfy the normality and constant variance assumption. To normalize the hardness data several transformations were applied. The one that gave the most reasonable result was the natural logarithm transformation. So for further analysis and optimization, natural logarithm of the hardness data was used. The regression models that were built included quadratic and interaction terms. In other words, responses were fit to second order model. The coefficient of determination values (r^2) of the four models were greater than 0.90. The coefficient of determination and R^2 values are provided in Table 3.8. The detailed regression models and ANOVA results for the models can be found in Appendix Table C.11-C.14. A comparison of predicted vs. real values of the responses are also available in Appendix (Fig. C.1-C.4). When the figures were examined it was seen that the predicted and experimental values did not differ significantly. This was a good indication that the regression models fitted were appropriate for the responses.

Table 3.8 Regression Models and r^2 values for the responses

M. Content = 12.4 - 3.26 MW Power** - 4.12 Frying Time*** - 3.27 OD Time** + 1.10 MW Power^{2} - 0.97 Frying Time^{2} + 0.74 OD Time^{2} + 0.49 MW Power*Frying Time - 0.17 MW Power*OD Time + 1.31 Frying Time*OD Time

r^2 = 94.6%

O. Content = 22.9 + 4.52 MW Power*** + 2.03 Frying Time** - 2.71 OD Time**- 2.55 MW Power$^{2\,(*)}$ + 1.44 Frying Time^{2} + 2.31 OD Time$^{2\,(*)}$ + 1.77 MW Power*Frying Time* - 0.558 MW Power*OD Time + 0.787 Frying Time*OD Time

r^2 = 98.7%

Color = 45.5 + 2.73 MW Power** + 0.884 Frying Time - 1.08 OD Time- 1.32 MW Power^{2} + 0.324 Frying Time^{2} + 1.78 OD Time^{2}+ 1.90 MW Power*Frying Time - 1.94 MW Power*OD Time+ 1.29 Frying Time*OD Time

r^2 = 92.8%

Hardness = 1.59 + 0.476 MW Power* + 0.412 Frying Time* + 0.312 OD Time* - 0.163 MW Power^{2} - 0.034 Frying Time^{2} + 0.095 OD Time^{2}- 0.327 MW Power*Frying Time - 0.194 MW Power*OD Time- 0.108 Frying Time*OD Time

r^2 = 91.8%

*Means term is significant at $p \leq 0.05$

**Means term is significant at $p \leq 0.01$

***Means term is significant at $p \leq 0.001$

In RSM, as the first step contour plots were drawn and examined. The contour plots were obtained by using the equations given in Table 3.8.

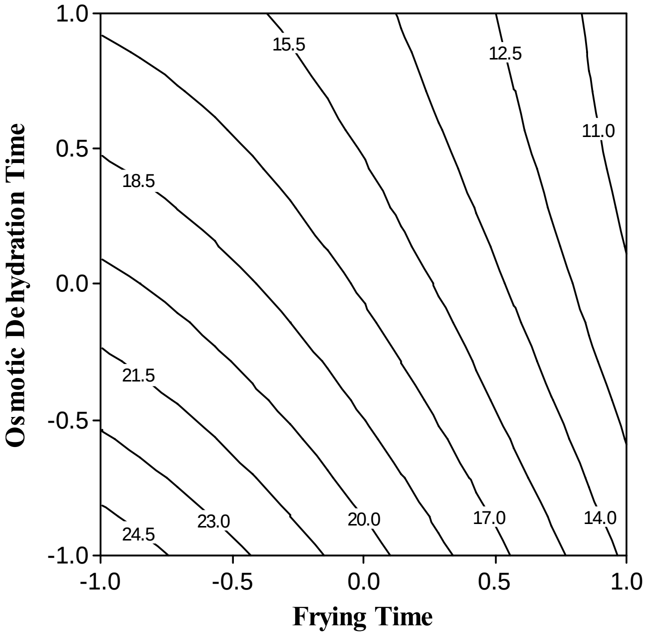

Figure 3.35 Contour plot showing the effect of osmotic dehydration time and frying time on moisture content of fried potatoes (Microwave Power = -1 (400 W))

As can seen in Fig. 3.35, as frying time increased, moisture content decreased. As osmotic dehydration time increased moisture content of fried potatoes decreased at power level of 400W. This was true for all power levels. From the contour plot, it was seen that as frying time increased osmotic dehydration time became less important in terms of moisture content. In other words, when frying time was above 2.0 (coded value of 0) minutes osmotic dehydration time became less effective on moisture content.

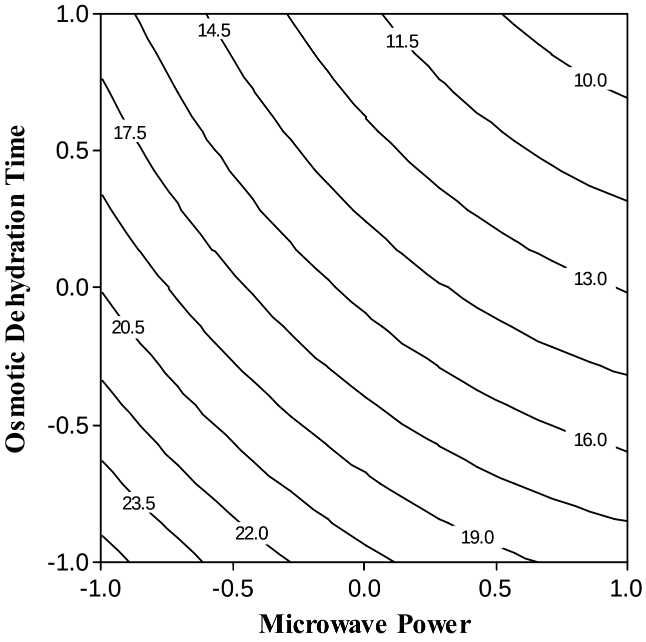

Figure 3.36 Contour plot showing the effect of osmotic dehydration time and microwave power level on moisture content of fried potatoes (Frying Time = -1 (1.5 min))

When microwave power level and osmotic dehydration time increased moisture content of the fried potatoes decreased for all frying times which were consistent with the previous results. Increase in microwave power level caused less reduction in moisture content than the increase in frying time (Fig. 3.37). In other words, frying time seemed to have more effect than the microwave power level. As mentioned before in the previous parts, above power level of 550 W there was no significant difference on affecting moisture content is detected. This result is also consistent with the contour plot.

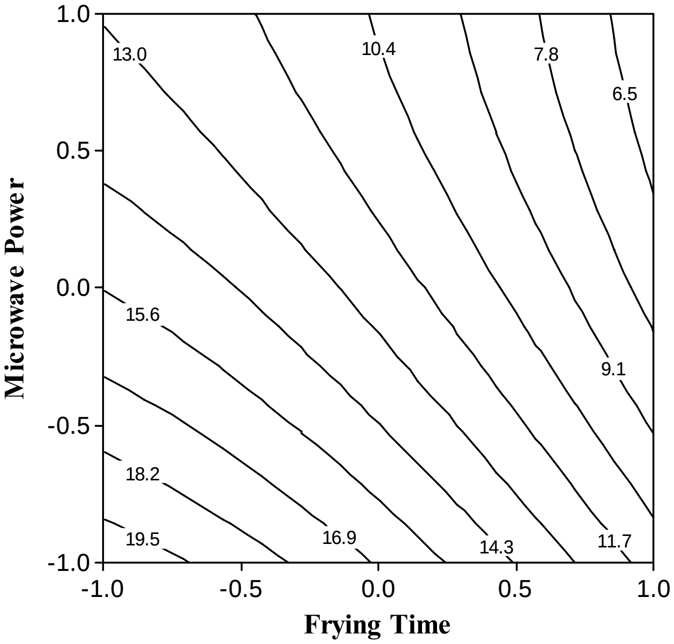

Figure 3.37 Contour plot showing the effect of microwave power level and frying time on moisture content of fried potatoes (Osmotic Dehydration Time = 0 (30 min))

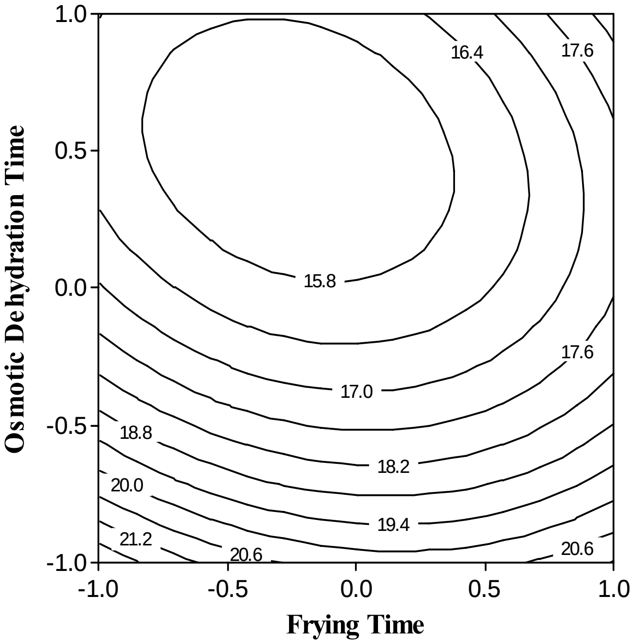

Figure 3.38 Contour plot showing the effect of osmotic dehydration time and frying time on oil content of fried potatoes (Microwave Power = -1 (400 W))

The contour plot in Figure 3.38 showed that an optimum point existed for oil content at power level of 400 W. According to the plot the minimum oil content was attainable when frying time was kept at the middle level (ie.-0.10) and osmotic dehydration time was kept at 0.5 in coded units. The increase in dehydration time increased oil content up to coded level of 0 (30 min) and thereafter it became almost constant. This is consistent with our previous results. This result is reasonable since as osmotic dehydration time decreases initial moisture content of the potatoes will be higher, moisture loss during frying will be higher. As a result oil uptake will be higher.

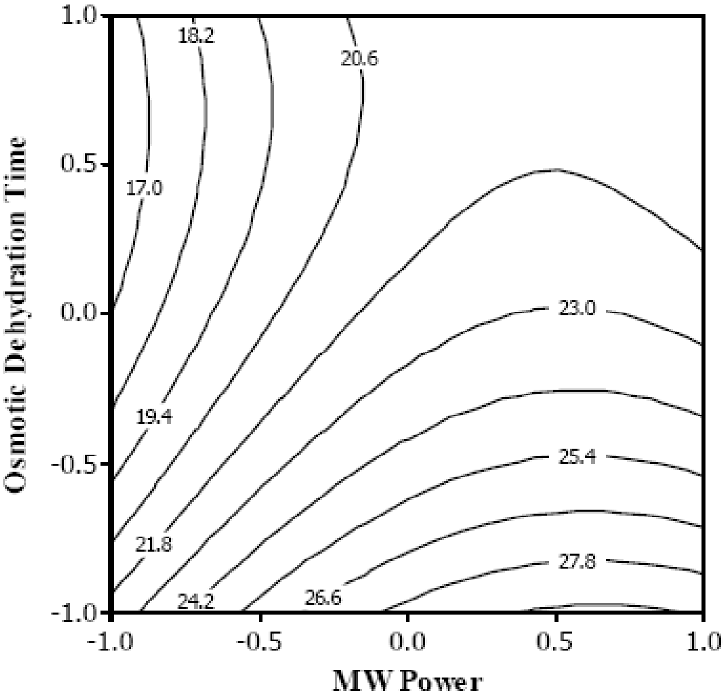

Figure 3.39 Contour plot showing the effect of osmotic dehydration time and microwave power level on oil content of fried potatoes (Frying Time = -1 (1.5 min))

Fig 3.39 also shows that the increase in osmotic dehydration time up to level 0 (30 min) decreased oil content whereas after level 0, osmotic dehydration time seemed to be ineffective on oil content. After that, oil content became dependent only on microwave power level. As microwave power level increased; oil content increased which was an expected result due to high moisture loss and then stated almost constant (Fig. 3.39-3.40). For low osmotic dehydration times the effect of microwave power level became insignificant after a certain level.

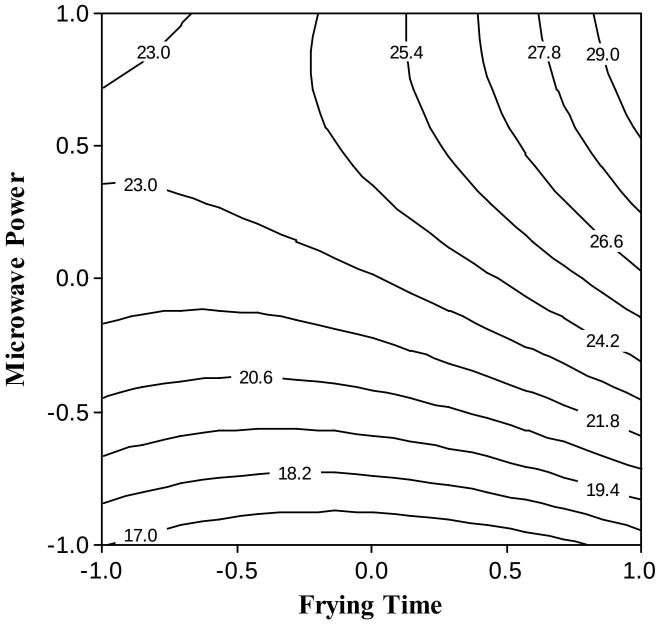

Figure 3.40 Contour plot showing the effect of frying time and microwave power level on oil content of fried potatoes (Osmotic Dehydration Time = 0 (30 min))

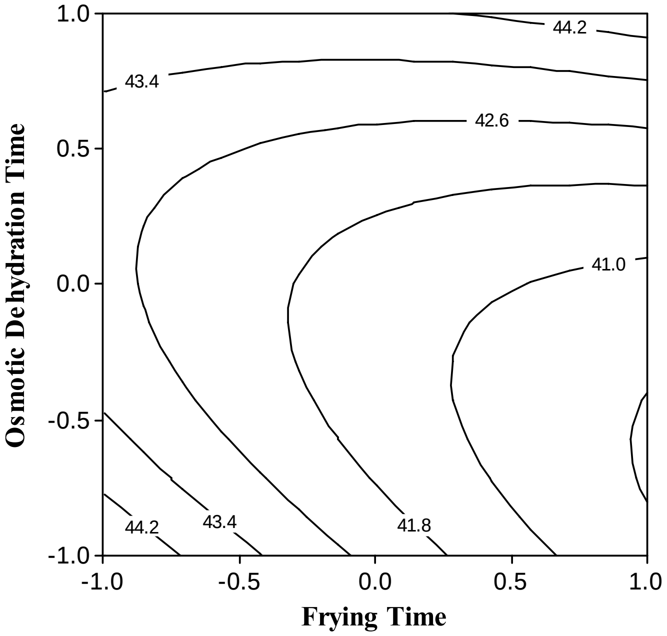

Figure 3.41 Contour plot showing the effect of osmotic dehydration time and frying time on ΔE of fried potatoes (Microwave Power = -1 (400 W))

According to Fig. 3.41, there is a minimum value for the color data. However, it is not desired to find the minimum, but the purpose was to find the one that was closest to the target (ΔE of the conventional frying; 49.08). It is obvious from the contour plot that to achieve target color lower frying times are needed. Osmotic dehydration time was seen to be not very significant on total color difference (Fig. 3.41 & 3.42). This result is consistent with the previous results. When the Tukey Test for color was performed it was found that 30 minutes and 45 minutes did not differ significantly.

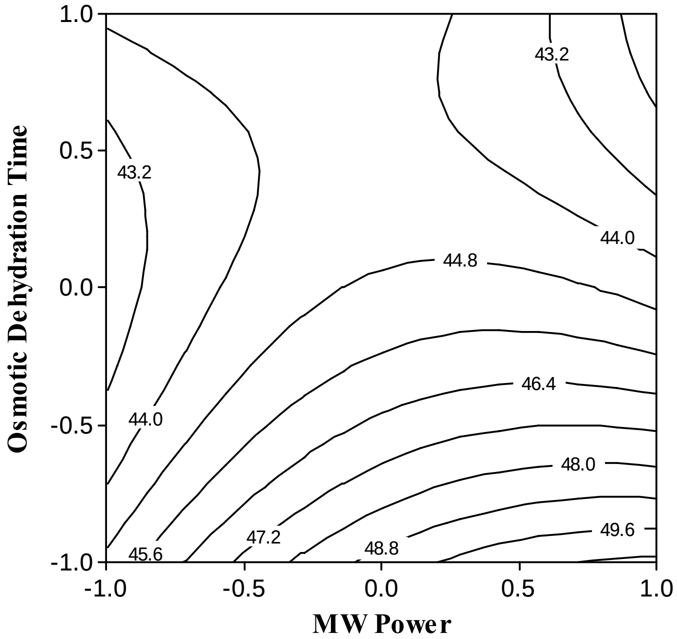

Figure 3.42 Contour plot showing the effect of osmotic dehydration time and microwave power level on ΔE of fried potatoes (Frying Time = -1 (1.5 min))

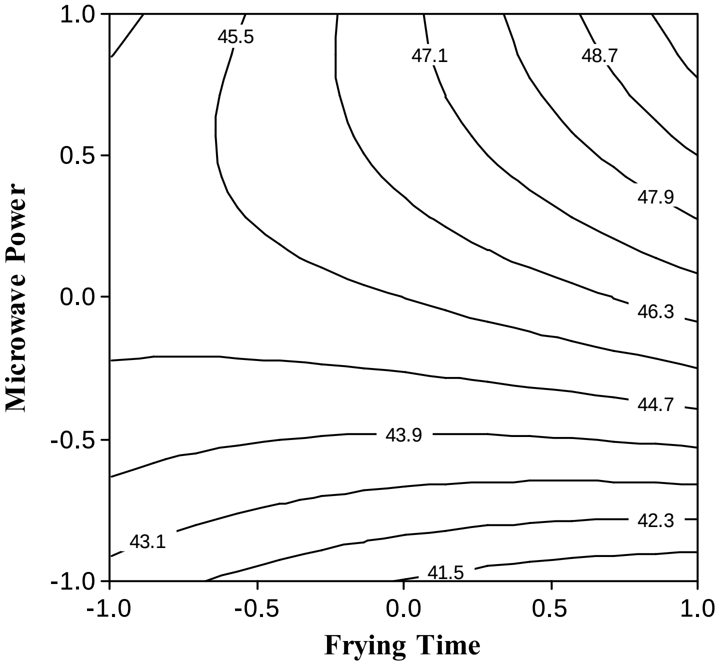

Figure 3.43 Contour plot showing the effect of frying time and microwave power level on ΔE of fried potatoes (Osmotic Dehydration Time = -1 (30 min))

From Fig. 3.43 it could be seen that at microwave power levels up to 0 level (550 W), frying time was not significant on total color difference whereas after that level ΔE value of the potatoes increased as frying time increased.

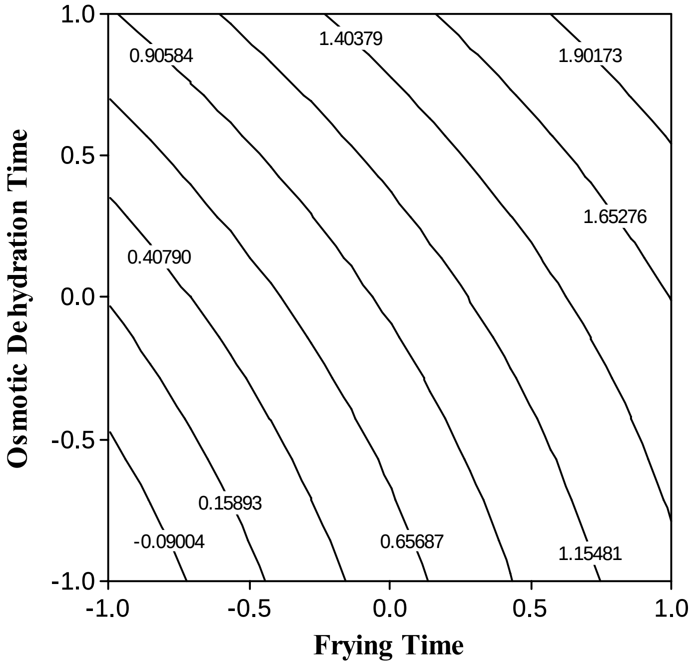

Figure 3.44[•] Contour plot showing the effect of osmotic dehydration time and frying time on hardness of fried potatoes (Microwave Power = -1 (400 W))

It can be seen from Fig. 3.44 & Fig. 3.45 that as osmotic dehydration time increased hardness of the fried potatoes increased. Frying time seemed to be more effective than osmotic dehydration time on increasing the hardness value of the fried potatoes.

[•] The presence of negative values are due to natural logarithm transformation

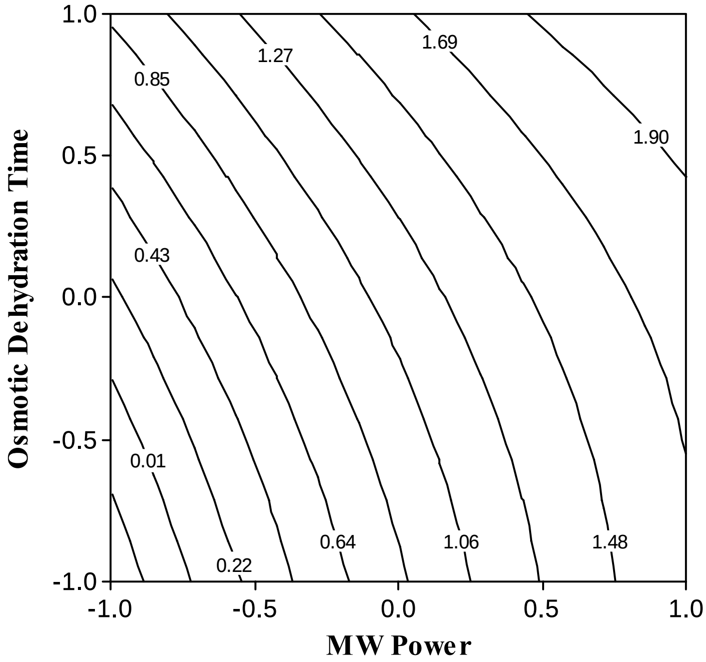

Figure 3.45 Effect of osmotic dehydration time and microwave power level on hardness of fried potatoes (Frying Time = -1 (1.5 min))

Hardness values of the fried potatoes also increased as microwave power level increased (Fig. 3.45). Microwave power level was more effective than osmotic dehydration time on increasing the hardness of the potatoes.

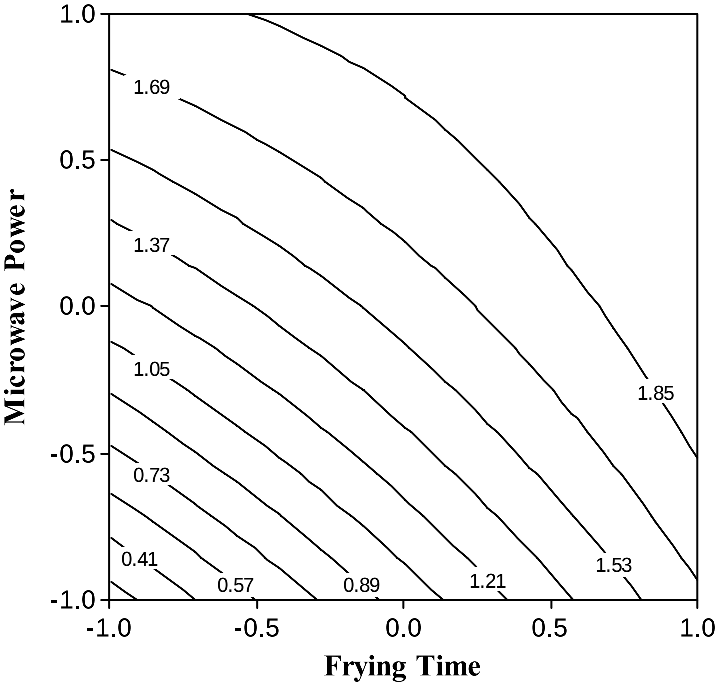

Figure 3.46 Contour plot showing the effect of frying time and microwave power level on hardness of fried potatoes (Osmotic Dehydration Time = -1 (30 min))

Fig. 3.46 also shows that hardness values of the fried potatoes increased as microwave power level and frying time increased. According to the figure microwave power level was slightly more effective than frying time on increasing the hardness of the potatoes.

For multiple response optimization option of the Minitab the data in Table 3.9 were used.

Table 3.9 Parameter Description for Multiple Response Optimizer

Response	Goal	Lower	Target	Upper	Weight	Importance
Moisture Content % (dry basis)	Maximize	4	22.68		5	1
Oil Content % (dry basis)	Minimize		15.73	41.28	10	4
Color (DE)	Target	40.77	49.08	52.84	5	3
ln_Hardness (N)	Target	0.0304	0.49262	2.1794	5	2

For hardness, the upper and lower values were taken as the hardest and softest values among the available data. For ΔE value , the smallest and greatest values were taken as upper and lower value. The targets were taken as the values of the conventionally fried potatoes that were not treated osmotically since they were considered as ‘acceptable’.

For moisture content, the maximum moisture content among the available data was taken since moisture contents of the conventionally fried potatoes that were not treated osmotically was 67.44 % (db). Since such a huge number was not available in the data, the largest of the available data was taken as the target. For the lower bound the lowest moisture content was taken.

For oil content the minimum oil content among the available data was taken since oil contents of the conventionally fried potatoes that were not treated osmotically was 41.28 % (db). As the upper bound 41.28 % (db) was taken. The relative importance of the parameters was the same ones that were used in Taguchi Technique.

The optimum condition from RSM was found to be -1, -1, and 0.583 in coded units for microwave power, frying time and osmotic dehydration time respectively. *Multiple Response Optimization* output of MINITAB is given in Table 3.10. The optimum condition corresponds to 400 W, 1.5 minutes frying time and 39 minutes osmotic dehydration time correspondingly. C The relationship between, moisture content, oil content, total color difference (ΔE), hardness and the independent variables of microwave power level, frying time and osmotic dehydration time were similar to the ones described previously.

Table 3.10 Multiple Response Optimization Results for RSM

Parameters	Goal	Lower	Target	Upper	Weight	Importance
M. Content % (db)	Maximum	4.00	22.68	22.68	5	1
O. Content % (db)	Minimum	15.73	15.73	41.28	10	4
Color (ΔE)	Target	40.77	49.08	52.84	2	3
Hardness (ln)	Target	0.0304	0.4926	2.1794	5	2

Global	Solution		Coded Units	Uncoded Units
MW	Power	=	-1	400
Frying	Time	=	-1	1.5 min
OD	Time	=	0.58325	39 min

Predicted	Responses					
M.	Content	=	18.0960,	desirability	=	0.2447
O.	Content	=	16.1152,	desirability	=	0.8591
Color		=	43.1581,	desirability	=	0.0827
Hardness	(ln)	=	0.5698,	desirability	=	0.7912
Hardness	Transformed	=	1.77			
Composite	Desirability	=	0.36928			

The individual desirabilities and the composite desirability of the responses are quite high. Especially for oil content desirability is satisfactory.

3.3 Comparison of the different frying methods

In this part of the study, microwave frying with and without osmotic dehydration and conventional frying methods will be compared in terms of the quality parameters. The comparison will be based on the optimum conditions found from different optimization techniques.

3.3.1 Moisture Content

As can be seen in Fig. 3.47, microwave fried potatoes had lower moisture content than conventionally fried ones. It was also obvious from the figure that the osmotically dehydrated microwave fried potatoes had lower moisture contents compared to others. The osmotic dehydration time for the optimum condition that was found with RSM was higher compared to the one found from the Taguchi technique. The higher osmotic dehydration time resulted in slightly lower moisture content.

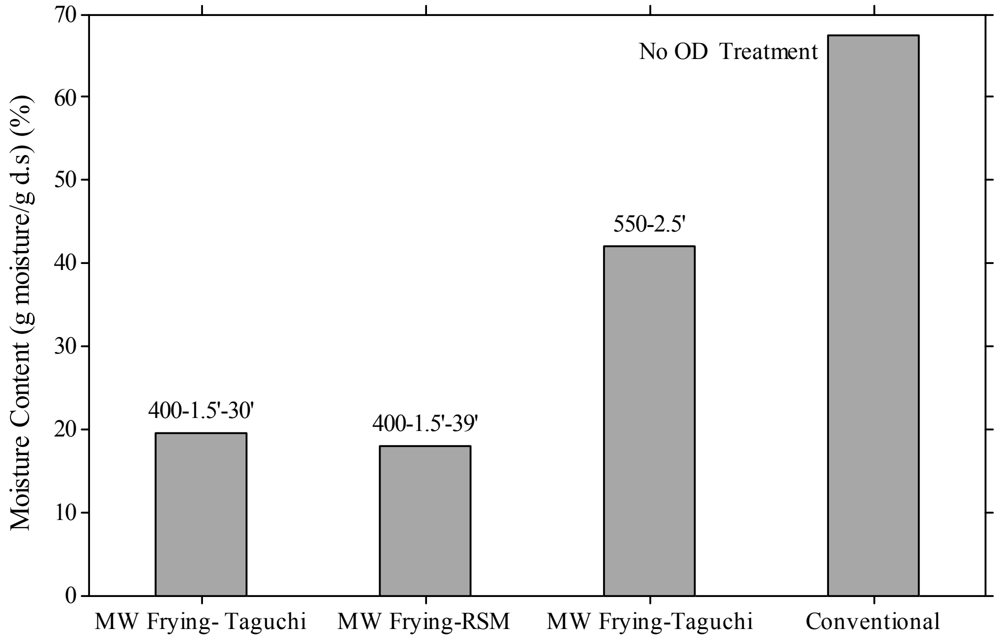

Figure 3.47 Comparison of moisture content of potatoes fried at different conditions.

The labels on the bars in Fig. 3.47 denote the frying conditions. The first number denotes, microwave power level, the second one denotes frying time and the third one is the osmotic dehydration time.

3.3.2 Oil Content

Despite high moisture loss, oil content of microwave fried potatoes was found to be lower than the conventionally fried ones (Fig. 3.48). This was explained by the low diffusion rate of oil compared to diffusion of water during frying. The oil content of osmotically dehydrated potatoes was low compared to the ones that were not dehydrated osmotically. This result confirmed the fact that osmotic dehydration was a good method to reduce oil uptake during frying.

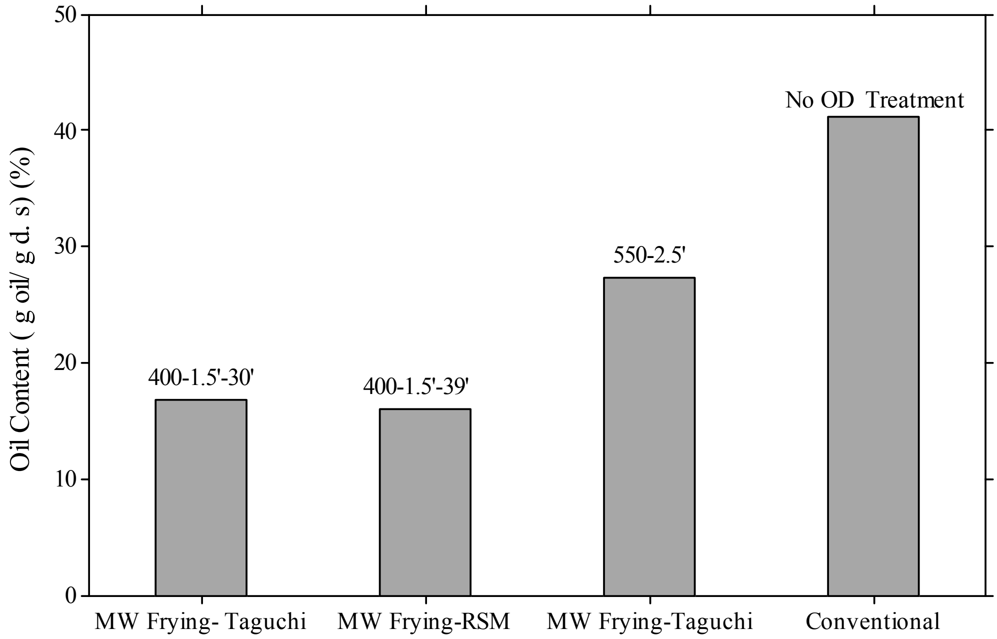

Figure 3.48 Comparison of oil content of potatoes fried at different conditions

3.3.3 Color

No significant difference was found in terms of total color difference between different frying methods. ΔE values of the osmotically dehydrated potatoes determined by the Taguchi and RSM techniques were almost equal. However, ΔE of the microwave fried potatoes that were not subjected to osmotic dehydration were closer to the control (conventionally fried potatoes' ΔE).

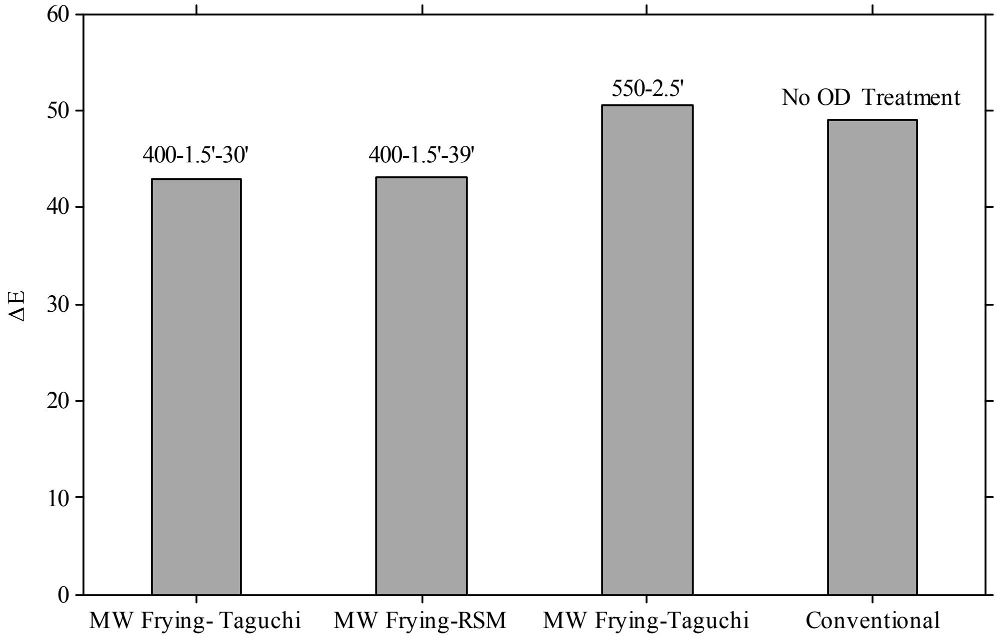

Figure 3.49 Comparison of ΔE value of potatoes fried at different conditions

3.3.4 Texture

According to the Fig. 3.50, the hardness of the microwave fried (without osmotic dehydration treatment) and conventionally fried potatoes were almost same. The lowest hardness values were observed for the microwave fried potatoes that were osmotically dehydrated (fried at optimum condition according to Taguchi). The hardest potatotes were obtained at the optimum condition determined by RSM due to high dehydration time. Previously it was shown that osmotic dehydration time was a significant factor on affecting hardness of the fried potatoes.

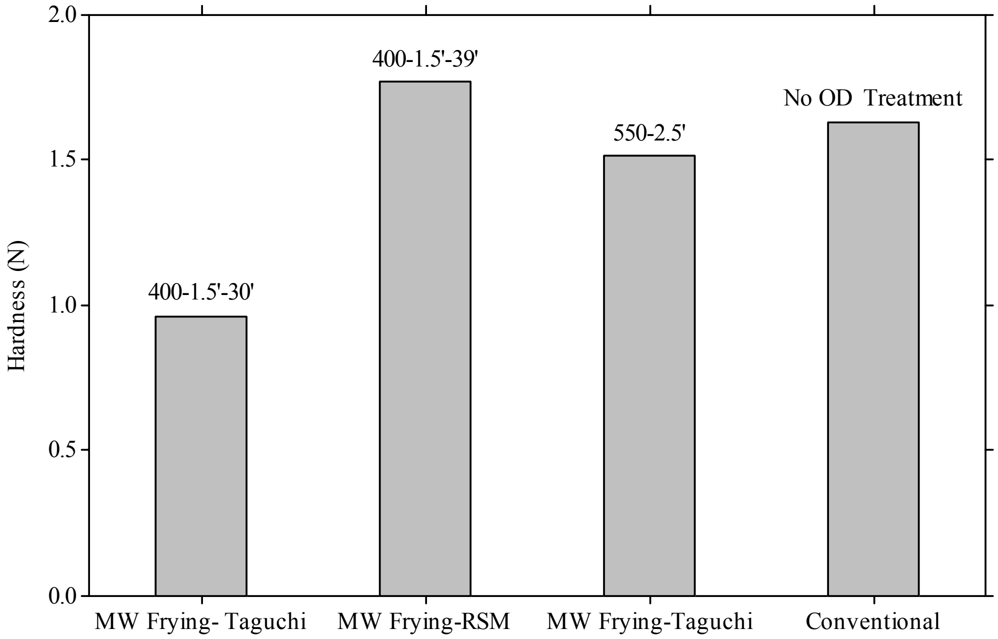

Figure 3.50 Comparison of the hardness of potatoes fried at different conditions

3.4 Comparison of the different optimization methods

The optimum conditions that were found from the two techniques were almost the same. This is a good proof that Taguchi Technique can be an alternative to RSM. RSM uses mathematical modeling to find the optimum condition whereas Taguchi is a pure statistical optimization technique. In RSM, it is not always possible to fit the appropriate model for the parameters. In that case RSM becomes insufficient and does not give reliable results. However, in Taguchi Technique it is not necessary to build regression models for the responses. In other words, Taguchi Technique eliminates one of the most important steps in RSM.

Another advantage of Taguchi Technique is that it enables use of qualitative variables in the optimization. However, in RSM when qualitative variables are present, the regression models may not be meaningful. In the first part of this study, it was possible to include oil type in optimization which was a qualitative variable.

As a result, Taguchi Technique can be considered as an easier optimization technique. But it is important to emphasize that when appropriate regression models are fitted and qualitative variables are not used, RSM is a more powerful tool than Taguchi Technique.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

In this study, microwave frying of the potatoes was studied. Using microwaves as a frying method decreased oil content of potatoes and frying time significantly, but increased moisture loss as compared to conventionally fried ones. No significant difference was detected between the color of microwave and conventionally fried potatoes. Higher oil content was observed in the case of both microwave and conventionally fried potatoes when hazelnut oil was used as the frying medium. Sunflower oil can be recommended as the medium to be used in microwave frying. Moisture content of potatoes decreased but color, hardness and oil content of potatoes increased as frying time and microwave power increased. Microwave power, frying time and oil type were found to be significant factors on affecting oil content, hardness and color of microwave fried potatoes. Since oil content of potatoes were significantly reduced when microwaves were used, microwave frying of the potatoes can be suggested as an alternative to conventional deep fat frying.

When osmotic dehydration was used as a pretreatment, the moisture content of the microwave fried potatoes was lower than the ones that were not treated osmotically. However, oil content of these potatoes decreased which supported the fact that osmotic dehydration was an effective method to reduce oil uptake in fried foods. However, the hardness of these potatoes increased. In that respect, different solutions and times for osmotic dehydration may be suggested. Moreover, potatoes may be coated with materials which have high penetration depth so that potatoes will not be heated too much and texture of the potatoes will be softer.

Further research is necessary to use microwave frying for frying of other vegetables and in the manufacturing of potato chips. As a final point, acrylamide content of the potatoes fried in microwave oven is expected to be lower since frying takes place in a shorter time as compared to conventional deep fat frying. In that respect, microwave fried potatoes may be healthier than the conventionally fried ones. However, this can be studied in a further research.

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APPENDIX A

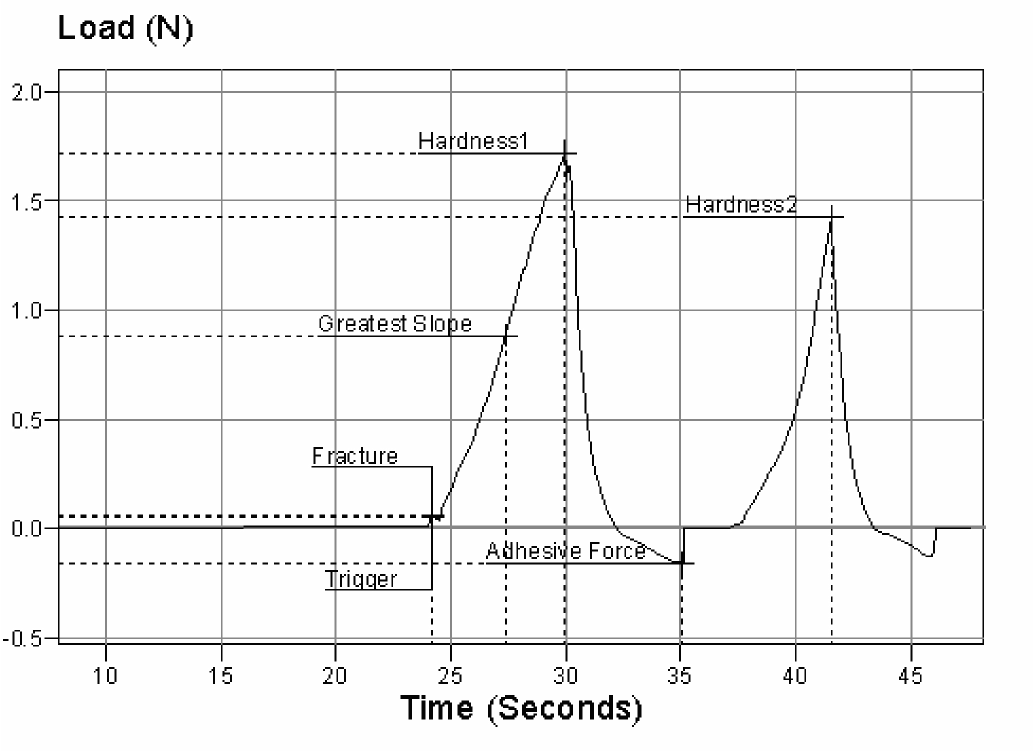


Figure A.1 Typical TPA curve for an osmotically dehydrated microwave potato

APPENDIX B

Table B.1 Experimental data for the microwave fried potatoes

MW Power Level	Frying Time (min)	Oil Type	Moisture Content (% db)	Oil Content (% db)	ΔE	Hardness (N)
400	2.00	Sunflower	157.51	16.32	41.8931	0.21617
400	2.50	Sunflower	79.64	18.13	43.401	0.82584
400	3.00	Sunflower	52.89	25.48	46.0966	2.36182
550	2.00	Sunflower	78.72	21.25	44.3088	0.76583
550	2.50	Sunflower	42.04	27.40	45.5074	1.51375
550	3.00	Sunflower	31.97	33.70	46.7068	3.63546
700	2.00	Sunflower	41.48	23.74	44.5596	0.87768
700	2.50	Sunflower	21.32	30.54	46.3694	1.70304
700	3.00	Sunflower	8.02	36.42	49.8177	6.03219
400	2.00	Corn	105.77	13.18	46.3555	0.25071
400	2.50	Corn	72.94	22.05	48.3228	0.33706
400	3.00	Corn	59.56	29.05	49.6999	0.39016
550	2.00	Corn	77.96	17.56	48.9551	0.36569
550	2.50	Corn	53.79	20.71	53.7255	1.79704
550	3.00	Corn	29.13	31.56	55.3844	2.56430
700	2.00	Corn	53.09	24.26	51.8394	0.40741
700	2.50	Corn	44.65	32.09	55.0365	1.80722
700	3.00	Corn	19.42	37.82	58.6973	7.12644
400	2.00	Hazelnut	150.58	42.19	45.2954	0.17574
400	2.50	Hazelnut	115.21	49.43	47.195	0.30548
400	3.00	Hazelnut	64.55	75.30	50.1922	1.04345
550	2.00	Hazelnut	96.65	48.67	45.9422	0.53048
550	2.50	Hazelnut	53.99	72.49	48.5248	1.82274
550	3.00	Hazelnut	39.80	79.75	52.3723	2.76624
700	2.00	Hazelnut	60.12	60.75	50.9624	0.59659
700	2.50	Hazelnut	40.52	74.48	52.6591	3.80956
700	3.00	Hazelnut	18.11	86.50	56.4479	5.78504

Table B.2 ANOVA Results for Moisture Content (Box-Cox Transformed) (% db)

Source	DF	Seq SS	Adj. SS	Adj. MS	F	p
MW Power	2	8.97	8.97	4.48	695.08	0.0000
Frying Time	2	7.34	7.34	3.67	568.44	0.0000
Oil Type	2	0.69	0.69	0.34	53.25	0.1340
MW Power x Frying Time	4	0.13	0.13	0.03	5.13	0.0030
MW Power x Oil Type	4	0.57	0.57	0.14	22.09	0.0000
Frying Time x Oil Type	4	0.20	0.20	0.05	7.70	0.0000
MW Power x Frying Time x Oil Type	8	0.19	0.19	0.02	3.75	0.0050
Error	27	0.17	0.17	0.01		
Total	53	18.26				

S= 0.0803 R-Sq= 99.05% R-Sq(adj) 98.1%

Table B.3 ANOVA Results for Oil Content (Box-Cox Transformed) (% db)

Source	DF	Seq SS	Adj. SS	Adj. MS	F	p
MW Power	2	0.01	0.01	0.01	23.86	0.0000
Frying Time	2	0.02	0.02	0.01	42.37	0.0000
Oil Type	2	0.11	0.11	0.06	198.96	0.0000
MW Power x Frying Time	4	0.00	0.00	0.00	0.50	0.7370
MW Power x Oil Type	4	0.00	0.00	0.00	2.14	0.1030
Frying Time x Oil Type	4	0.00	0.00	0.00	1.55	0.2170
MW Power x Frying Time x Oil Type	8	0.00	0.00	0.00	0.80	0.6110
Error	27	0.01	0.01	0.00		
Total	53	0.16				

S= 0.0168 R-Sq= 95.35% R-Sq(adj) 90.9%

Table B.4 ANOVA Results for Color (ΔE)

Source	DF	Seq SS	Adj. SS	Adj. MS	F	p
MW Power	2	65.28	65.28	32.64	10.01	0.0010
Frying Time	2	143.47	143.47	71.74	22.00	0.0000
Oil Type	2	24.21	24.21	12.11	3.71	0.0380
MW Power x Frying Time	4	6.32	6.32	1.58	0.48	0.7470
MW Power x Oil Type	4	40.82	40.82	10.21	3.13	0.0310
Frying Time x Oil Type	4	13.01	13.01	3.25	1.00	0.4260
MW Power x Frying Time x Oil Type	8	2.73	2.73	0.34	0.10	0.9990
Error	27	88.05	88.05	3.26		
Total	53	383.90				

S=	1.8059	R-Sq=	77.06%	R-Sq(adj)	55.0%

Table B.5 ANOVA Results for Hardness (N) (Natural Logarithm Transformed)

Source	DF	Seq SS	Adj. SS	Adj. MS	F	p
MW Power	2	21.72	21.72	10.86	136.84	0.0000
Frying Time	2	31.23	31.23	15.62	196.71	0.0000
Oil Type	2	2.04	2.04	1.02	12.86	0.0000
MW Power x Frying Time	4	1.12	1.12	0.28	3.54	0.0190
MW Power x Oil Type	4	1.51	1.51	0.38	4.76	0.0050
Frying Time x Oil Type	4	0.26	0.26	0.07	0.83	0.5160
MW Power x Frying Time x Oil Type	8	3.45	3.45	0.43	5.44	0.0000
Error	27	2.14	2.14	0.08		
Total	53	63.49				

Table B.6 Tukey Test Results for M. Content (% db)) (Box-Cox Transformed)

Tukey Simultaneous Tests

MW POWER = 400 subtracted from:

MW Power	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
550	-0.5316	0.0268	-19.8500	0.0000
700	-0.9976	0.0268	-37.2600	0.0000
MW Power	550	Subtracted from		
700	-0.4660	0.0268	-17.4000	0.0000

Tukey Simultaneous Tests

Frying Time =2.0 subtracted from:

Frying Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
2.5	-0.4497	0.0268	-16.7900	0.0000
3.0	-0.9028	0.0268	-33.7200	0.0000
Frying Time	2.0	Subtracted from		
3.0	-0.4531	0.0268	-16.9200	0.0000

Tukey Simultaneous Tests

Oil Type =Corn subtracted from:

Oil Type	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
H.N	0.1637	0.0268	6.1130	0.1387
S.F	-0.1110	0.0268	-4.1440	0.0963
OD Time	H.N	Subtracted from		
S.F	-0.2746	0.0268	-10.2600	0.1487

Table B.7 Tukey Test Results for O. Content (% db)) (Box-Cox Transformed)

Tukey Simultaneous Tests

MW POWER = 400 subtracted from:

MW Power	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
550	-0.5316	0.0268	-19.8500	0.0000
700	-0.9976	0.0268	-37.2600	0.0000
MW Power	550	Subtracted from		
700	-0.4660	0.0268	-17.4000	0.0000

Tukey Simultaneous Tests

Frying Time =2.0 subtracted from:

Frying Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
2.5	-0.4497	0.0268	-16.7900	0.0000
3.0	-0.9028	0.0268	-33.7200	0.0000
Frying Time	2.0	Subtracted from		
3.0	-0.4531	0.0268	-16.9200	0.0000

Tukey Simultaneous Tests

Oil Type =Corn subtracted from:

Oil Type	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
H.N	0.1637	0.0268	6.1130	0.0000
S.F	-0.1110	0.0268	-4.1440	0.0009
OD Time	H.N	Subtracted from		
S.F	-0.2746	0.0268	-10.2600	0.0000

Table B.8 Tukey Test Results for Color (ΔE)

Tukey Simultaneous Tests

MW POWER = 400 subtracted from:

MW Power	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
550	1.5400	0.6020	2.5590	0.0421
700	2.6840	0.6020	4.4580	0.0004
MW Power	550	Subtracted from		
700	1.1430	0.6020	1.8990	0.1583

Tukey Simultaneous Tests

Frying Time =2.0 subtracted from:

Frying Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
2.5	1.8710	0.6020	3.1090	0.0119
3.0	3.9900	0.6020	6.6290	0.0000
Frying Time	2.0	Subtracted from		
3.0	2.1190	0.6020	3.5200	0.0043

Tukey Simultaneous Tests

Oil Type =Corn subtracted from:

Oil Type	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
H.N	-1.5410	0.6020	-2.5600	0.0420
S.F	-1.2570	0.6020	-2.0890	0.1112
OD Time	H.N	Subtracted from		
S.F	0.2837	0.6020	0.4713	0.8853

Table B.9 Tukey Test Results for Hardness (N) (Natural Logarithm Transformed)

Tukey Simultaneous Tests

MW POWER = 400 subtracted from:

MW Power	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
550	1.0800	0.0939	11.5000	0.0000
700	1.5070	0.0939	16.0500	0.0000
MW Power	550	Subtracted from		
700	0.4270	0.0939	4.5470	0.0003

Tukey Simultaneous Tests

Frying Time =2.0 subtracted from:

Frying Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
2.5	1.0660	0.0939	11.3500	0.0000
3.0	1.8560	0.0939	19.7600	0.0000
Frying Time		2.0 Subtracted from		
3.0	0.7903	0.0939	8.4150	0.0000

Tukey Simultaneous Tests

Oil Type =Corn subtracted from:

Oil Type	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
H.N	0.2392	0.0939	2.5470	0.0432
S.F	0.4762	0.0939	5.0710	0.0001
OD Time		H.N Subtracted from		
S.F	0.2370	0.0939	2.5230	0.0455

Table B.10 Summary of Tukey Test Results

	p value			
	M. Content	Oil Content	Color (ΔE)	Hardness (N)
MW POWER = 400 subtracted from:				
MW Power				
550	0.0000	0.0000	0.0424	0.0000
700	0.0000	0.0000	0.0004	0.0000
MW POWER = 550 subtracted from:				
MW Power				
700	0.0000	0.0000	0.1583	0.0003
Frying Time = 2.0 min subtracted from:				
Frying Time				
2.5	0.0000	0.0000	0.0119	0.0000
3.0	0.0000	0.0000	0.0000	0.0000
Frying Time = 2.5 min subtracted from:				
3.0	0.0000	0.0000	0.0043	0.0000
Oil Type= Corn subtracted from:				
Oil Type				
Hazel Nut	0.1387	0.0000	0.0042	0.0432
Sunflower	0.0963	0.0009	0.1112	0.0010
Oil Type= Hazel nut subtracted from:				
Sunflower	0.1487	0.0000	0.8853	0.0455

APPENDIX C

Table C.1 Experimental data for osmotically dehydrated fried potatoes

MW POWER	Frying Time	OD Time	M. Content (% dry basis)	Oil Content (% dry basis)	ΔE	Hardness (N)
400	1.50	15	28.37	17.98	45.69	0.48158
400	2.00	15	24.09	21.21	44.78	1.77862
400	2.50	15	14.67	22.83	43.56	3.73025
400	1.50	30	19.58	16.88	43.07	0.96437
400	2.00	30	16.54	16.98	41.94	2.10934
400	2.50	30	11.43	17.14	41.18	5.41202
400	1.50	45	17.44	15.65	44.32	1.75466
400	2.00	45	15.96	15.73	42.98	5.48130
400	2.50	45	9.97	16.10	41.89	6.42585
550	1.50	15	22.68	27.43	47.62	2.59217
550	2.00	15	14.56	27.87	47.27	4.83554
550	2.50	15	10.75	30.16	47.01	6.02486
550	1.50	30	16.18	21.68	43.78	4.52307
550	2.00	30	12.41	22.93	44.90	4.99898
550	2.50	30	8.53	27.76	45.50	8.39608
550	1.50	45	11.02	21.63	44.62	4.90520
550	2.00	45	9.31	21.80	46.37	7.13013
550	2.50	45	4.31	27.51	47.78	8.73071
700	1.50	15	19.16	28.50	46.35	4.63838
700	2.00	15	12.88	30.78	51.74	5.90633
700	2.50	15	10.06	33.78	54.66	7.51733
700	1.50	30	12.68	22.96	43.85	5.93538
700	2.00	30	10.46	23.30	44.67	7.15650
700	2.50	30	6.49	30.29	50.81	8.11574
700	1.50	45	10.26	24.27	42.54	6.19610
700	2.00	45	8.52	23.06	45.12	7.74107
700	2.50	45	4.35	29.43	51.43	9.65589
Conventional with 15 min. OD			20.75	27.83	47.38	1.33651
Conventional with 30 min. OD			16.37	17.79	45.43	3.42603
Conventional with 45 min. OD			12.82	17.95	46.05	6.49053
Conventional Without OD			67.44	41.28	49.08	1.63313

Table C.2 ANOVA Results for Moisture Content (% db)

Source	DF	Seq SS	Adj. SS	Adj. MS	F	p
MW Power	2	414.19	414.19	207.10	38.60	0.0000
Frying Time	2	655.84	655.84	327.92	61.11	0.0000
OD Time	2	430.84	430.84	215.42	40.15	0.0000
MW Power x Frying Time	4	11.98	11.98	2.99	0.56	0.6950
MW Power x OD Time	4	12.84	12.84	3.21	0.60	0.6670
Frying Time x OD Time	4	69.96	69.96	17.49	3.26	0.0260
MW Power x Frying Time x OD Time	8	3.64	3.64	0.46	0.08	0.9990
Error	27	145.00	144.88	5.37		
Total	53	1744.00				

S= 2.32 R-Sq= 91.69% R-Sq(adj) 83.7%

Table C.3 ANOVA Results for Oil Content (% db)

Source	DF	Seq SS	Adj. SS	Adj. MS	F	p
MW Power	2	914.61	914.61	457.30	64.98	0.0000
Frying Time	2	183.19	183.19	91.59	13.01	0.0000
OD Time	2	276.21	276.21	138.10	19.62	0.0000
MW Power x Frying Time	4	42.69	42.69	10.67	1.52	0.2250
MW Power x OD Time	4	5.45	5.45	1.36	0.19	0.9400
Frying Time x OD Time	4	10.12	10.12	2.53	0.36	0.8350
MW Power x Frying Time x OD Time	8	25.61	25.61	3.20	0.45	0.8770
Error	27	190.00	190.01	7.04		
Total	53	1648.00				

S= 2.65 R-Sq= 88.47% R-Sq(adj) 77.4%

Table C.4 ANOVA Results for Color (ΔE)

Source	DF	Seq SS	Adj. SS	Adj. MS	F	p
MW Power	2	249.31	249.31	124.66	31.47	0.0000
Frying Time	2	79.31	79.31	39.66	10.01	0.0010
OD Time	2	84.47	84.47	42.24	10.66	0.0000
MW Power x Frying Time	4	200.53	200.53	50.13	12.66	0.0000
MW Power x OD Time	4	60.41	60.41	15.10	3.81	0.0140
Frying Time x OD Time	4	16.30	16.30	4.07	1.03	0.4110
MW Power x Frying Time x OD Time	8	33.95	33.95	4.24	1.07	0.4120
Error	27	107.00	109.95	3.96		
Total	53	831.00				

S= 1.99 R-Sq= 87.13% R-Sq(adj) 74.7%

Table C.5 ANOVA Results for Hardness (N) (Box-Cox Transformed)

Source	DF	Seq SS	Adj. SS	Adj. MS	F	p
MW Power	2	1.01	1.01	0.50	49.17	0.0000
Frying Time	2	0.63	0.63	0.32	30.78	0.0000
OD Time	2	0.29	0.29	0.14	14.12	0.0000
MW Power x Frying Time	4	0.13	0.13	0.03	3.16	0.0300
MW Power x OD Time	4	0.05	0.05	0.01	1.26	0.3100
Frying Time x OD Time	4	0.02	0.02	0.00	0.45	0.7700
MW Power x Frying Time x OD Time	8	0.03	0.03	0.00	0.38	0.9230
Error	27	0.28	0.28	0.01		
Total	53	2.44				

S= 0.10132 R-Sq= 88.64% R-Sq(adj) 77.7%

Table C.6 Tukey Test Results for Moisture Content (% db)

Tukey Simultaneous Tests
Response Variable M.Content %
All Pairwise Comparisons among Levels of Microwave Power

MW POWER = 400 subtracted from:

MW Power	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
550	-4.8700	0.7721	-6.3080	0.0000
700	-6.5250	0.7721	-8.4500	0.0000
MW Power	550	Subtracted from		
700	-1.6540	0.7721	-2.1430	0.1000

Tukey Simultaneous Tests
Response Variable M.Content %
All Pairwise Comparisons among Levels of Frying Time

Frying Time =1.5 subtracted from:

Frying Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
2.0	-4.1180	0.7721	-5.3300	0.0000
2.5	-8.5350	0.7721	-11.0500	0.0000
Frying Time	2.0	Subtracted from		
2.5	-4.4170	0.7721	-5.7200	0.0000

Tukey Simultaneous Tests
Response Variable M.Content %
All Pairwise Comparisons among Levels of OD Time

OD Time =15 subtracted from:

OD Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
30	-4.2760	0.7721	-5.5370	0.0000
45	-6.8490	0.7721	-8.8700	0.0000
OD Time	30.0	Subtracted from		
45	-2.5730	0.7721	-3.3320	0.0069

Table C.7 Tukey Test Results for Oil Content (% db)

Tukey Simultaneous Tests
Response Variable O.Content %
All Pairwise Comparisons among Levels of Microwave Power

MW POWER = 400 subtracted from:

MW Power	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
550	7.5870	0.8843	8.5800	0.0000
700	9.5420	0.8843	10.7910	0.0000
MW Power	550	Subtracted from		
700	1.9550	0.8843	2.2110	0.0874

Tukey Simultaneous Tests
Response Variable O.Content %
All Pairwise Comparisons among Levels of Frying Time

Frying Time =1.5 subtracted from:

Frying Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
2.0	0.7414	0.8843	0.8385	0.6828
2.5	4.2247	0.8843	4.7776	0.0002
Frying Time	2.0 Subtracted from			
2.5	3.4830	0.8843	3.9390	0.0015

Tukey Simultaneous Tests
Response Variable O.Content %
All Pairwise Comparisons among Levels of OD Time

OD Time =15 subtracted from:

OD Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
30	-4.5120	0.8843	-5.1020	0.0001
45	-5.0400	0.8843	-5.6990	0.0000
OD Time	30.0 Subtracted from			
45	-0.5279	0.8843	-0.5969	0.8229

Table C.8 Tukey Test Results for Color (ΔE)

Tukey Simultaneous Tests
Response Variable Color
All Pairwise Comparisons among Levels of Microwave Power

MW POWER = 400 subtracted from:

MW Power	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
550	3.1460	0.6634	4.7420	0.0002
700	5.2270	0.6634	7.8790	0.0000
MW Power	550	Subtracted from		
700	2.0820	0.6634	3.1380	0.0110

Tukey Simultaneous Tests
Response Variable Color
All Pairwise Comparisons among Levels of Frying Time

Frying Time =1.5 subtracted from:

Frying Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
2.0	0.4039	0.6634	0.6088	0.8166
2.5	2.7489	0.6634	4.1436	0.0009
Frying Time	2.0	Subtracted from		
2.5	2.3450	0.6634	3.5350	0.0041

Tukey Simultaneous Tests
Response Variable Color
All Pairwise Comparisons among Levels of OD Time

OD Time =15 subtracted from:

OD Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
30	-3.0460	0.6634	-4.5920	0.0003
45	-1.8060	0.6634	-2.7220	0.0292
OD Time	30.0	Subtracted from		
45	1.2400	0.6634	1.8690	0.1671

Table C.9 Tukey Test Results for Hardness (Box-Cox Transformed)

Tukey Simultaneous Tests
Response Variable Hardness
All Pairwise Comparisons among Levels of Microwave Power
MW POWER = 400 subtracted from:

MW Power	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
550	0.2443	0.0338	7.2320	0.0000
700	0.3206	0.0338	9.4920	0.0000
MW Power	550	Subtracted from		
700	0.0763	0.0338	2.2600	0.0792

Tukey Simultaneous Tests
Response Variable Hardness
All Pairwise Comparisons among Levels of Frying Time
Frying Time =1.5 subtracted from:

Frying Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
2.0	0.1450	0.0338	4.2930	0.0006
2.5	0.2646	0.0338	7.8340	0.0000
Frying Time	2.0	Subtracted from		
2.5	0.1196	0.0338	3.5410	0.0041

Tukey Simultaneous Tests
Response Variable Hardness
All Pairwise Comparisons among Levels of OD Time
OD Time =15 subtracted from:

OD Time	Difference of Means	SE of Difference	T- Value	Adjusted P-Value
30	0.0927	0.0338	2.7430	0.0279
45	0.1795	0.0338	5.3130	0.0000
OD Time	30.0	Subtracted from		
45	0.0868	0.0338	2.5700	0.0411

Table C.10 Summary of Tukey Test Results

	p value			
	M. Content	Oil Content	Color (ΔE)	Hardness (N)
MW POWER = 400 subtracted from:				
MW Power				
550	0.0000	0.0000	0.0002	0.0000
700	0.0000	0.0000	0.0000	0.0000
MW POWER = 550 subtracted from:				
MW Power				
700	0.1000	0.0874	0.0110	0.0792
Frying Time = 1.5 min subtracted from:				
Frying Time				
2.0	0.0000	0.6828	0.8166	0.0006
2.5	0.0000	0.0002	0.0009	0.0000
Frying Time = 2.0 min subtracted from:				
2.5	0.0000	0.0015	0.0041	0.0041
Osmotic Dehydration Time= 15 min subtracted from:				
Osmotic Dehydration Time				
30	0.0000	0.0001	0.0003	0.0279
45	0.0000	0.0000	0.0292	0.0000
Osmotic Dehydration Time= 30 min subtracted from:				
45	0.0000	0.8229	0.1671	0.0411

Table C.11 Oil Content (% db) of fried potatoes under different frying condition

MW Power	Frying Time (min)	Osmotic Dehydration (OD) Time (min)	Oil Content % (g oil/ g dry solid)
400	1.50	15	17.98
400	2.00	15	21.21
400	2.50	15	22.83
400	1.50	30	16.88
400	2.00	30	16.98
400	2.50	30	17.14
400	1.50	45	15.65
400	2.00	45	15.73
400	2.50	45	16.10
550	1.50	15	27.43
550	2.00	15	27.87
550	2.50	15	30.16
550	1.50	30	21.68
550	2.00	30	22.93
550	2.50	30	27.76
550	1.50	45	21.63
550	2.00	45	21.80
550	2.50	45	27.51
700	1.50	15	28.50
700	2.00	15	30.78
700	2.50	15	33.78
700	1.50	30	22.96
700	2.00	30	23.30
700	2.50	30	30.29
700	1.50	45	24.27
700	2.00	45	23.06
700	2.50	45	29.43
400	2.0	None	16.32
400	2.5	None	18.13
400	3.0	None	25.48
550	2.0	None	21.25
550	2.5	None	27.40
550	3.0	None	33.70
700	2.0	None	23.74
700	2.5	None	30.54
700	3.0	None	36.42
		Frying Time	
Conventional Frying with OD for 15 min.		4.0	27.83
Conventional Frying with OD for 30 min		4.0	17.79
Conventional Frying with OD for 45 min		4.0	17.95
Conventional Frying Without OD		4.5	41.28
Conventional Frying With Drying		4.0	32.60

Table C.12 CIE L, a, b and ΔE values for Fried Potatoes

MW Power	Frying Time	OD Time	L	a	b	ΔE
400	1.50	15'	67.62	1.72	42.23	45.69
400	2.00	15'	70.07	2.53	42.96	44.78
400	2.50	15'	72.66	2.70	43.29	43.56
550	1.50	15'	67.12	1.70	44.32	47.62
550	2.00	15'	67.51	4.20	43.98	47.27
550	2.50	15'	65.86	5.32	42.10	47.01
700	1.50	15'	62.15	2.38	37.78	46.35
700	2.00	15'	60.14	10.21	42.15	51.74
700	2.50	15'	56.04	14.85	40.34	54.66
Conventional (OD Time=15')			63.14	4.16	40.18	47.38
400	1.50	30'	70.55	2.44	41.18	43.07
400	2.00	30'	74.50	2.73	42.56	41.94
400	2.50	30'	74.44	4.25	41.46	41.18
550	1.50	30'	71.86	2.45	43.04	43.78
550	2.00	30'	68.05	5.72	41.13	44.90
550	2.50	30'	67.33	6.66	41.13	45.50
700	1.50	30'	70.68	4.98	41.98	43.85
700	2.00	30'	67.72	8.33	39.98	44.67
700	2.50	30'	63.19	12.27	43.18	50.81
Conventional (OD Time=30')			63.275	5.875	37.175	45.43
400	1.50	45'	70.48	3.54	42.61	44.32
400	2.00	45'	73.00	2.03	42.86	42.98
400	2.50	45'	74.88	3.70	42.65	41.89
550	1.50	45'	71.58	6.30	43.40	44.62
550	2.00	45'	69.68	7.01	44.08	46.37
550	2.50	45'	66.48	9.62	42.76	47.78
700	1.50	45'	68.88	2.10	39.13	42.54
700	2.00	45'	68.25	5.49	41.63	45.12
700	2.50	45'	62.37	12.20	43.31	51.43
Conventional (OD Time=45')			67.84	4.5	42.64	46.05
Conventional Without OD			68.8125	3.8125	47.15	49.0752
MW Frying with Conv. Drying			62.57	5.55	46.70	52.17

Table C.13 Hardness of fried potatoes under different frying conditions

MW Power	Frying Time (min)	Osmotic Dehydration (OD) Time (min)	Hardness (N)
400	1.50	15	0.48158
400	1.50	30	0.96437
400	1.50	45	1.75466
400	2.00	15	2.59217
400	2.00	30	4.52307
400	2.00	45	4.90520
400	2.50	15	4.63838
400	2.50	30	5.93538
400	2.50	45	6.19610
550	1.50	15	1.77862
550	1.50	30	2.10934
550	1.50	45	5.48130
550	2.00	15	4.83554
550	2.00	30	4.99898
550	2.00	45	7.13013
550	2.50	15	5.90633
550	2.50	30	7.15650
550	2.50	45	7.74107
700	1.50	15	3.73025
700	1.50	30	5.41202
700	1.50	45	6.42585
700	2.00	15	6.02486
700	2.00	30	8.39608
700	2.00	45	8.73071
700	2.50	15	7.51733
700	2.50	30	8.11574
700	2.50	45	9.65589
400	2.0	None	0.21617
400	2.5	None	0.82584
400	3.0	None	2.36182
550	2.0	None	0.76583
550	2.5	None	1.51375
550	3.0	None	3.63546
700	2.0	None	0.87768
700	2.5	None	1.70304
700	3.0	None	6.03219
		Frying Time	
Conventional Frying with OD for 15 min.		4.0	1.33651
Conventional Frying with OD for 30 min		4.0	3.42603
Conventional Frying with OD for 45 min		4.0	6.49053
Conventional Frying Without OD		4.5	1.63313
Conventional Frying With Drying to 186.25 % m.c (g moisture / g dry solid)		4.0	0.82887

Table C.14 Response Surface Analysis Results for Moisture Content

Estimated Regression Coefficients for Moisture Content

Term	Coefficient	SE Coefficent	T	P
Constant	12.415	1.5264	8.133	0.001
MW Power	-3.2562	0.7632	-4.266	0.013
Frying Time	-4.1225	0.7632	-5.401	0.006
OD Time	-3.2688	0.7632	-4.283	0.013
MW Power*MW Power	1.0962	1.2067	0.908	0.415
Frying Time* Frying Time	-0.9662	1.2067	-0.801	0.468
OD Time* OD Time	0.7413	1.2067	0.614	0.572
MW Power*Frying Time	0.49	1.0793	0.454	0.673
MW Power * OD Time	-0.1675	1.0793	-0.155	0.884
Frying Time*OD Time	1.305	1.0793	1.209	0.293

S= 2.159 R-Sq= 94.60% R-Sq(adj) = 82.30%

Analysis of Variance for M. Content

Source	DF	Seq SS	Adj SS	Adj MS	F	p
Regression	9	324.454	324.454	36.05	7.74	0.0320
Linear	3	306.263	306.263	102.088	21.91	0.0060
Square	3	10.306	10.306	3.435	0.74	0.5820
Interaction	3	7.885	7.885	2.628	0.56	0.6670
Residual Error	4	18.64	18.64	4.66		
Lack-of-Fit	3	15.639	15.639	5.213	1.74	0.4970
Pure Error	1	3.001	3.001	3.001		
Total	13	343.093				

Table C.15 Response Surface Analysis Results for Oil Content

Estimated Regression Coefficients for Oil Content

Term	Coefficient	SE Coefficent	T	P
Constant	22.9338	0.7275	31.523	0.0000
MW Power	4.5161	0.3638	12.415	0.0000
Frying Time	2.0259	0.3638	5.569	0.0050
OD Time	-2.7064	0.3638	-7.44	0.0020
MW Power*MW Power	-2.5524	0.5752	-4.438	0.0110
Frying Time* Frying Time	1.435	0.5752	2.495	0.0670
OD Time* OD Time	2.3119	0.5752	4.02	0.0160
MW Power*Frying Time	1.7665	0.5144	3.434	0.0260
MW Power * OD Time	-0.5583	0.5144	-1.085	0.3390
Frying Time*OD Time	0.7874	0.5144	1.531	0.2010

S= 1.029 R-Sq= 98.70% R-Sq(adj) = 95.80%

Analysis of Variance for O. Content

Source	DF	Seq SS	Adj SS	Adj MS	F	p
Regression	9	325.661	325.661	36.1846	34.18	0.0020
Linear	3	254.592	254.592	84.864	80.17	0.0000
Square	3	54.861	54.861	18.2869	17.27	0.0090
Interaction	3	16.209	16.209	5.4029	5.1	0.0750
Residual Error	4	4.234	4.234	1.0586		
Lack-of-Fit	3	3.627	3.627	1.209	1.99	0.4700
Pure Error	1	0.607	0.607	0.6074		
Total	13	329.896				

Table C.16 Response Surface Analysis Results for Color

Estimated Regression Coefficients for Color				
Term	Coefficient	SE Coefficent	T	p
Constant	45.51	1.1281	40.343	0.0000
MW Power	2.7263	0.564	4.833	0.0080
Frying Time	0.8838	0.564	1.567	0.1920
OD Time	-1.08	0.564	-1.915	0.1280
MW Power*MW Power	-1.3212	0.8918	-1.482	0.2130
Frying Time* Frying Time	0.3238	0.8918	0.363	0.7350
OD Time* OD Time	1.7813	0.8918	1.997	0.1160
MW Power*Frying Time	1.8975	0.7977	2.379	0.0760
MW Power * OD Time	-1.94	0.7977	-2.432	0.0720
Frying Time*OD Time	1.285	0.7977	1.611	0.1820

S= 1.595 R-Sq= 92.80% R-Sq(adj) = 76.50%

Analysis of Variance for Color						
Source	DF	Seq SS	Adj SS	Adj MS	F	p
Regression	9	130.843	130.8426	14.5381	5.71	0.0540
Linear	3	75.039	75.0388	25.0129	9.83	0.0260
Square	3	19.742	19.7425	6.5808	2.59	0.1910
Interaction	3	36.061	36.0613	12.0204	4.72	0.0840
Residual Error	4	10.18	10.1804	2.5451		
Lack-of-Fit	3	9.86	9.8604	3.2868	10.27	0.2250
Pure Error	1	0.32	0.32	0.32		
Total	13	141.023				

Table C.17 Response Surface Analysis Results for Hardness

Estimated Regression Coefficients for ln_Hardness

Term	Coefficient	SE Coefficent	T	p
Constant	1.59225	0.2296	6.934	0.0020
MW Power	0.47592	0.1148	4.145	0.0140
Frying Time	0.41204	0.1148	3.589	0.0230
OD Time	0.31196	0.1148	2.717	0.0530
MW Power*MW Power	-0.16312	0.1815	-0.899	0.4200
Frying Time* Frying Time	-0.03442	0.1815	-0.19	0.8590
OD Time* OD Time	0.09498	0.1815	0.523	0.6280
MW Power*Frying Time	-0.32714	0.1624	-2.015	0.1140
MW Power * OD Time	-0.19371	0.1624	-1.193	0.2990
Frying Time*OD Time	-0.10792	0.1624	-0.665	0.5430

S= 0.3247 R-Sq= 92.80% R-Sq(adj) = 73.30%

Analysis of Variance for ln_Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	p
Regression	9	4.71481	4.71481	0.52387	4.97	0.0690
Linear	3	3.94877	3.94877	1.31626	12.48	0.0170
Square	3	0.14125	0.14125	0.04708	0.45	0.7330
Interaction	3	0.62478	0.62478	0.20826	1.97	0.2600
Residual Error	4	0.42181	0.42181	0.10545		
Lack-of-Fit	3	0.09074	0.09074	0.03025	0.09	0.9550
Pure Error	1	0.33108	0.33108	0.33108		
Total	13	5.13662				

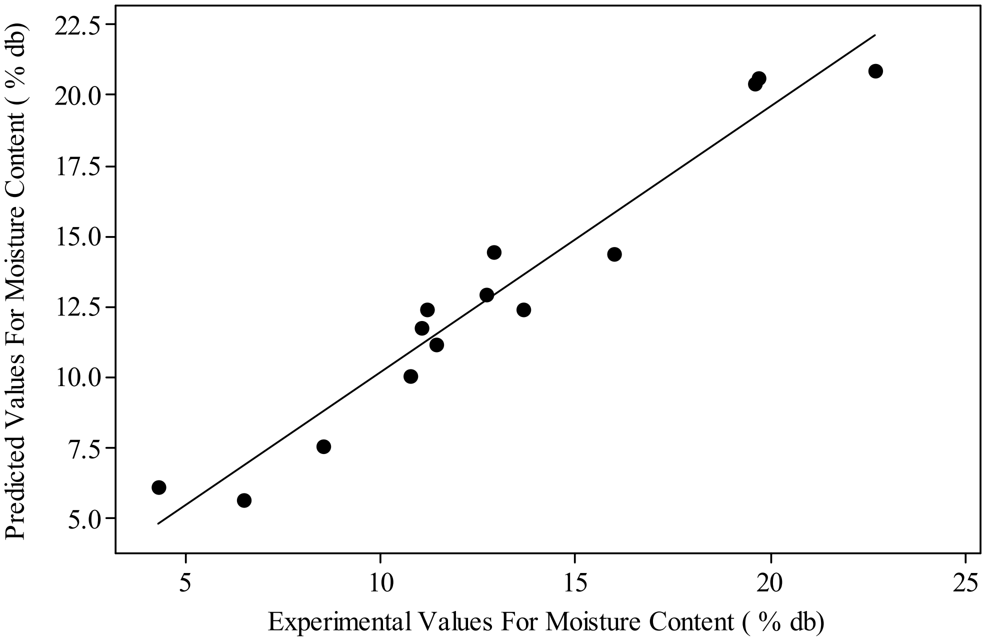


Figure C.1 Comparison of Predicted vs. Experimental Values of Moisture Content

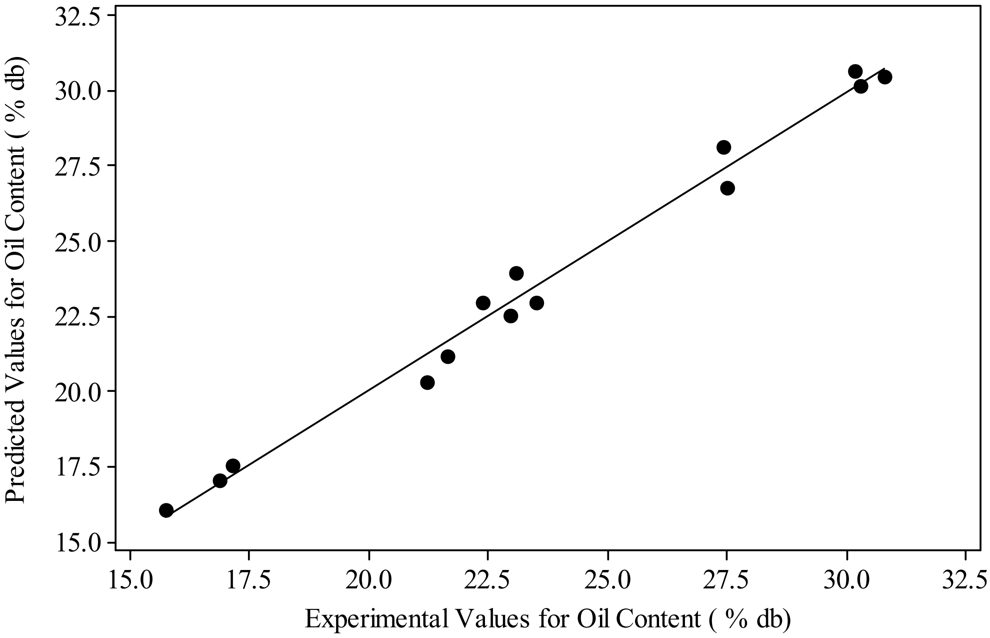


Figure C.2 Comparison of Predicted vs. Experimental Values of Oil Content

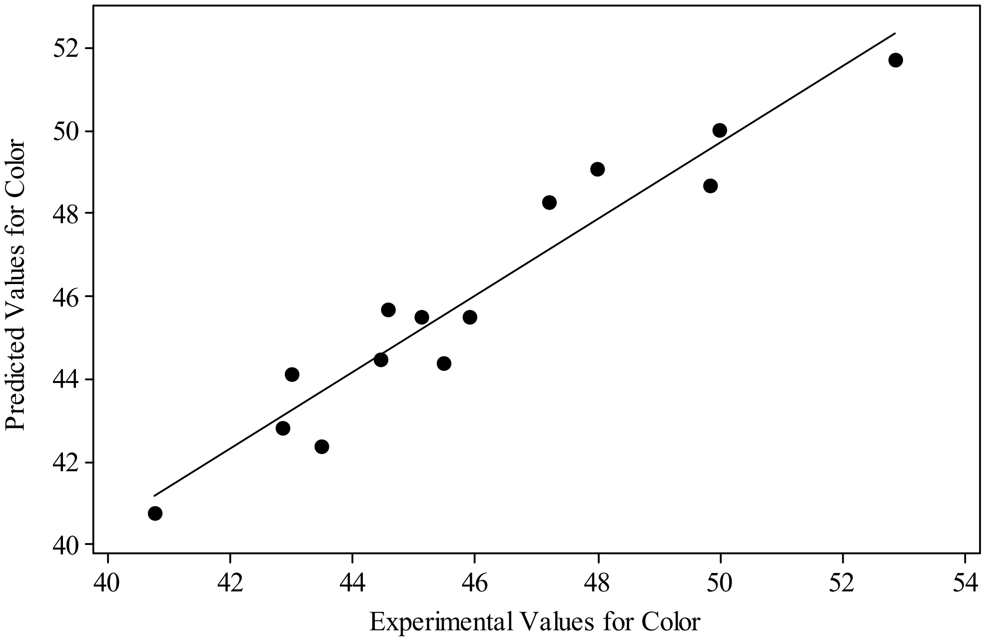


Figure C.3 Comparison of Predicted vs. Experimental Values of Color (ΔE)

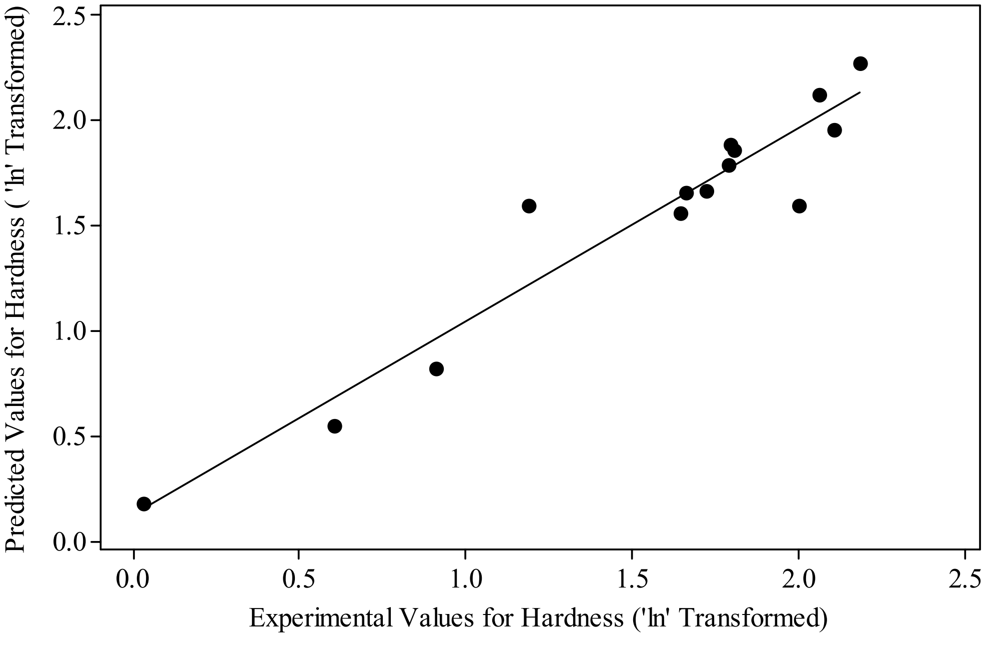


Figure C.4 Comparison of Predicted vs. Fitted Values of Hardness

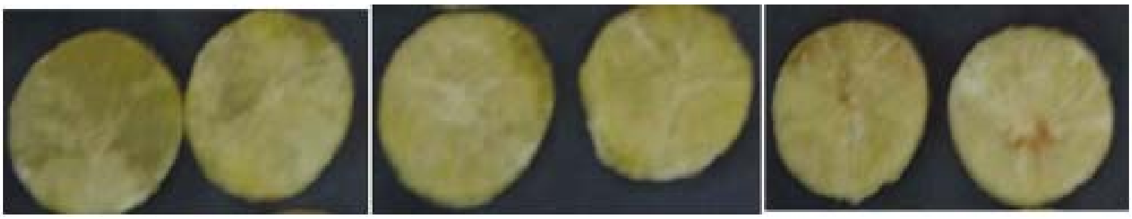
APPENDIX D

400 W-1.5’-30’ [2]   400 W-2.0’-30’   400 W-2.5’-30’

Figure D.1 Effect of Frying Time on the Color of Osmotically Dehydrated Microwave Fried Potatoes

400 W-1.5’-15’   400 W-1.5’-30’   400 W-1.5’-45’

Figure D.2 Effect of Osmotic Dehydration Time on the Color Osmotically Dehydrated Microwave Fried Potatoes



400 W-1.5-30’   550 W-1.5-30’   700 W-1.5-30’

Figure D.3 Effect of Microwave Power on the Color of Osmotically Dehydrated Microwave Fried Potatoes

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[2] First number represents microwave power level, second one represents frying time (min) and the third one represents osmotic dehydration time (min).

Figure D.4 Microwave fried potatoes after conventionally dried