# EFFECTS OF DIFFERENT BATTER FORMULATIONS ON PHYSICAL AND CHEMICAL PROPERTIES OF MICROWAVE AND CONVENTIONALLY FRIED CHICKEN FINGERS

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# EFFECTS OF DIFFERENT BATTER FORMULATIONS ON PHYSICAL AND CHEMICAL PROPERTIES OF MICROWAVE AND CONVENTIONALLY FRIED CHICKEN FINGERS

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

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# ABSTRACT

## EFFECTS OF DIFFERENT BATTER FORMULATIONS ON PHYSICAL AND CHEMICAL PROPERTIES OF MICROWAVE AND CONVENTIONALLY FRIED CHICKEN FINGERS

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The main objective of this study was to determine the effects of batters containing various flour types and frying methods on physical and chemical properties of chicken fingers.

To determine the effects of different flour types, 30 % of the corn and wheat flour mix in control batter was replaced with chickpea, rice or soy flours. Frying was performed in microwave oven at 365 W (70 %) power level and at 180±1°C for different times. Samples were also fried in a conventional fryer at 180±1°C for comparison. The properties that were measured were coating pick-up and moisture content, oil content, color, hardness, porosity and acrylamide content of fried samples. In addition, microstructural analysis of batters and temperature distribution of fried samples during cooling were performed.

Moisture content of chicken fingers decreased whereas the darkness, porosity and hardness of samples increased with increasing microwave frying time. Using microwaves decreased frying time by 70 %. Samples fried for 1.5 min using microwave provided similar moisture and oil contents in the coating part as compared to conventionally fried ones for 5min. However, the chicken part of microwave fried sample had lower moisture content. Lighter colored samples with higher porosity and lower hardness values were obtained with microwave frying. In microwave frying, soy flour addition to batter formulation decreased the moisture loss and oil absorption as compared to control by 19.3% and 20.7%, respectively. The lowest hardness, the highest porosity and oil content were obtained with the addition of chickpea flour.

Flour type was not found to be effective on acrylamide content. Microwave frying provided lower acrylamide content as compared to those fried conventionally for all types of flours. The reduction in acrylamide level was the highest (34.5%) for rice flour containing batter. Color parameters of chicken fingers were not found to be a reliable indicator of acrylamide levels.

Different types of frying method and flours used in batter formulation resulted in differences in the microstructure of fried batter.

Variations in internal temperature distribution during cooling increased with frying time in both microwave and conventional frying. The sample fried in microwave oven for 1.5 min had a more nonuniform temperature distribution.

Keywords: Acrylamide, Batter, Chicken Finger, Flour, Microwave Frying, Scanning Electron Microscopy (SEM), Temperature Mapping

# ÖZ

## FARKLI KAPLAMA MADDESİ FORMÜLASYONLARININ MİKRODALGADA VE KONVANSİYONEL YÖNTEM İLE KIZARTILMIŞ TAVUKLARIN FİZİKSEL VE KİMYASAL ÖZELLİKLERİ ÜZERİNE ETKİSİ

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Bu çalışmanın temel amacı farklı un tipleri içeren hamurların ve kızartma yönteminin tavuk ürünlerinin fiziksel ve kimyasal özellikleri üzerine etkilerinin araştırılmasıdır.

Kaplama hamurunda farklı un tiplerinin etkisini incelemek için, kontrol hamurundaki buğday ve mısır ununun %30'u pirinç, nohut veya soya unu ile ikame edilmiştir. Kızartma işlemi, mikrodalga fırında 365 W (%70) gücünde ve 180±1°C' de farklı kızartma sürelerinde gerçekleştirilmiştir. Örnekler ayrıca karşılaştırma amaçlı olarak geleneksel derin yağda, 180±1°C' de kızartılmıştır. Ölçülen özellikler kaplama hamurunun tutunması ve kızarmış ürünlerin nem miktarı, yağ miktarı, renk, sertlik, gözeneklilik değerleri ile akrilamid miktarlarıdır. Bunun yanı sıra hamurların mikroyapısal analizleri yapılmış ve kızartılan örneklerin soğuma sırasındaki sıcaklık dağılımları incelenmiştir.

Artan mikrodalga kızartma süresi ile, tavuk ürünlerinin nem içeriği azalmış, renk koyuluğu, gözeneklilik ve sertlik değerleri ise artmıştır. Mikrodalga kullanılması kızartma süresini %70 oranında kısaltmıştır. Mikrodalga ile 1,5 dakika kızartılan ürünler, geleneksel derin yağda 5,0 dakika kızartılan ürünler ile karşılaştırıldığında, kaplama maddesinde benzer nem ve yağ içeriği, tavuk kısmında ise daha düşük nem içeriği elde edilmiştir. Mikrodalgada kızartma işlemi ile daha açık renk ile daha yüksek gözeneklilik ve daha düşük sertlik değerlerine sahip ürünler elde edilmiştir. Hamur formülasyonuna soya unu eklenmesi, kontrol ile karşılaştırıldığında, nem kaybını %19,3 oranında ve yağ emilimini %20,7 oranında azaltmıştır. En düşük sertlik, en yüksek gözeneklilik ve yağ miktarı kaplama hamuruna nohut unu eklenmesi ile elde edilmiştir.

Un tipinin akrilamid miktarı üzerinde etkili olmadığı bulunmuştur. Mikrodalgada kızartma işlemi, geleneksel yöntem ile kızartılan ürünlere göre tüm un tipleri için daha düşük akrilamid oranı sağlamıştır. Akrilamid seviyesindeki azalma pirinç unu içeren kaplama hamurunda en yüksektir (34,5%). Tavuk ürünlerinin renk parametrelerinin akrilamid seviyesini belirlemede güvenilir bir gösterge olmadığı gözlenmiştir.

Farklı kızartma yöntemleri ve farklı kaplama hamurundaki un tipleri kızartılmış hamurun mikroyapısı üzerinde farklılığa neden olmuştur.

Sıcaklık dağılımındaki değişim her iki kızartma yönteminde de artan kızartma süresi ile artmaktadır. Mikrodalga fırında 1,5 dakika süre ile kızartılan ürün diğerlerine göre daha düzensiz sıcaklık dağılımına sahiptir.

Anahtar Kelimeler: Akrilamid, Kaplama Hamuru, Mikrodalgada Kızartma, Sıcaklık Dağılımı, Taramalı Elektron Mikroskobu, Tavuk, Un

*To my family*

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# INTRODUCTION

## 1.1 Conventional Deep Fat Frying

Frying is a fast and convenient technique for the production of foods with unique sensory properties of colour, flavour, texture, and palatability. Deep-fat frying can be defined as the process of drying and cooking through contact with hot oil (Sahin et al., 1999).

Deep fat frying is a process of simultaneous heat and mass transfer. Heat is transferred from the oil to the food and oil penetrates the crust through the pores created by the evaporation of water from the food. So, fat uptake is largely determined by the moisture content of the food (Gamble et al., 1987; Saguy and Pinthus, 1995; Southern et al., 2000). Especially at high moisture contents, vapor protects the food from oil absorption by creating an overpressure inside the pores. This barrier property of vapor probably continues until a few seconds after removal of the food from the oil. After taking the food out of the fryer, the temperature drops and the vapor in the pores condenses (Mellema, 2003). This condensation mechanism creates vacuum effect, which causes the adhering oil being pulled into the product. Gamble et al. (1987) were pioneers in initially explaining the mechanism of oil absorption. They suggested that most of the oil enters the surface at damaged areas after frying, from the adhering surface oil being pulled into the chip when it is removed from the fryer due to the condensation of steam.

Heat is transferred by convection from the oil to the surface of the product and by conduction within the food. When the food is immersed in oil, surface temperature of the food rapidly reaches the boiling point of water and steam bubbles start to leave the surface. Due to the evaporation, surface drying is seen. The evaporation also leads to shrinkage and crust formation (Mellema, 2003). Pravisani and Calvelo (1986) proposed the existence of an evaporating moving boundary towards the center that separates crust and the internal region. It was shown by many researchers that while the temperature in the internal region increases rapidly and stays constant around the boiling point of water (Farkas et al., 1996; Vitrac et al., 2000; Velez-Ruiz et al., 2002); the crust temperature continues to rise above the boiling point of water (Farkas et al., 1996; Hubbard and Farkas, 2000). The formation of crust is a significant quality index for fried foods. Crust characteristics such as color, surface roughness, depth and texture are functions of several factors, such as the food constituents, the frying temperature and duration, and the quality of frying oil. There is sufficient evidence that crust structural characteristic is the main factor influencing mass transfer during frying (Aguilera and Gloria, 1997; Pinthus et al., 1995a).

Vapor bubbling is related to water loss rate and decreases after reaching a maximum value with increasing frying time (Costa et al., 1997; Hubbard and Farkas, 2000). Drying rate affects the value of the heat transfer coefficient. The oil agitation caused by the increased rate of vapor loss promotes higher heat transfer rates (Costa et al., 1999; Hubbard and Farkas, 2000). However, there is some evidence that water vapor bubbles form a very poorly conductive gas layer around the sample and may result in an additional resistance to heat transfer (Fellows, 1996; Costa et al., 1999). Sahin et al. (1999) have found different convective heat transfer coefficients at the top and bottom surfaces of potatoes during frying which created an asymmetric temperature profile within the sample.

There are physical and chemical changes taking place during deep frying. Chemical changes are observed in the fried substance due to the effect of temperature and water losses. Also, some chemical interactions occur between food and frying oil. Reported alterations of chemical composition are generally much higher at the surface and nearly negligible in deeper layers.

Proteins are always present in fried foods in greater or lesser amounts. Amino acids and peptides are present in smaller quantities than proteins, but they are much more reactive. The main reaction of proteins during frying is denaturation. As the denaturation temperature is lower than 100°C, the protein fraction is denatured even in inner layers of fried food; this may influence the water holding capacity. Some biologically active substances, such as enzymes, are deactivated under frying conditions; therefore, fried products are usually more stable in storage than raw foods (Boskou and Elmadfa, 1999). Starch gelatinization is another crucial reaction in frying: it holds water and provides volume expansion. Protein denaturation and starch gelatinization are typical phenomena of the combined effect of multiple order chemical reactions. Kadan et al. (1997) clearly showed that protein/starch ratio is a factor in optimizing the textures of both the interior portion and the crust.

The main reactions contributing to the appreciated golden browning of fried foods are considered to be those between proteins and carbohydrates in the complex mechanism of the Maillard reaction. Various intermediate products rapidly polymerized at frying temperatures into brown colored macromolecular melanoidins. The browning becomes very rapid at temperatures higher than 150°C. In the case of fried meat products, the crust browning is not simply due to Maillard reactions, thermal degradation of amino acids and proteins may also participate in browning reactions. An agreeable flavor is the main reason that fried foods are produced and widely accepted. The typical fried flavor is mainly due to lipid degradation products originating from frying oils, but various specific components of fried substances contribute to the overall flavor. Therefore, it is possible to distinguish between flavors of different fried foods (Boskou and Elmadfa, 1999).

## 1.2 Microwave Frying

Microwaves are part of the electromagnetic spectrum and are located between the frequencies of 300 MHz and 30 GHz. Microwave heating is defined as the heating of a substance by electromagnetic energy operating in that frequency range (Risman, 1991).

Electric field component of microwave is responsible for heating of foods. The alternating electric field stimulates the oscillation of the dipoles of the molecules in the food. These dipolar molecules try to align with microwave field at a speed consistent with the microwave frequency. This rapid movement of polar molecules results in the development of heat, because of the friction between molecules (Knutson et al., 1987). Another mechanism responsible for heat generation is ionic polarization. Ionic polarization occurs when ions in solution move in response to the applied electric field component of microwave. Ions are accelerated by this electric field. Displacement of ions causes collision with other ions, converting kinetic energy into heat (Decareau and Peterson, 1986). At microwave frequencies, numerous collisions occur, and much heat is generated.

During microwave or high frequency heating, many material properties affect the heating performance. Among the most significant are the electromagnetic properties, especially the dielectric properties of the food. The dielectric properties describe how materials interact with electromagnetic radiation. The fundamental electrical property through which the interactions are described is the complex relative permittivity of the material. It is mathematically expressed by the following equation (Risman, 1991);

$$\varepsilon = \varepsilon^{'} - j\varepsilon^{''} \qquad (1.1)$$

The real component of the permittivity, known also as the dielectric constant (ε'), is related to the capacitance of a substance and its ability to store electrical energy. The imaginary component, the dielectric loss factor (ε''), is the ability of food material to dissipate electrical energy as heat.

Dielectric properties of food products are primarily determined by their chemical composition and, to a much lesser extent, by their physical structure. The influence of water and salt (or ash) content depends to a large extent on the manner in which they are bound or restricted in their movement by the other food components. This complicates the prediction of the dielectric properties of a mixture, based on data for single ingredients (Mudgett, 1995). Microwave heating is greatly affected by the presence of water in foods (Nelson and Kraszewski, 1990). Water is the major absorber of microwave energy in the foods and consequently, the higher the moisture content, the faster the heating. The physical state of water in a food affects also microwave heating. Low moisture foods have more uniform heating rate because of deeper microwave penetration (Mudgett, 1989). Salts dissolved in aqueous solutions act as conductors in an electromagnetic field. They simultaneously depress the permittivity and elevate the dielectric loss factor compared to the behavior of pure water (Mudgett, 1995; Bengtsson and Risman, 1971). The temperature dependence of the dielectric constant is quite complex, and it may increase or decrease with temperature depending on the material (Venkatesh and Raghavan, 2004).

After the heat is generated, it is transferred by conduction within the food. The heating rate depends on the thermal properties while absorbed power on the dielectric properties. In foods, thermal conductivity depends mostly on composition but also on many factors that affects the heat flow paths through the material, such as percent void spaces, shape, size and arrangement of void spaces and homogeneity (Sweat, 1995). Food with high thermal conductivity will take less time to attain uniform temperature during holding period. Specific heat of food determines how fast a food can be heated. Specific heat can be raised by increasing solid content with the addition of components like salt and protein.

Besides the electromagnetic and thermal properties many other factors affect how foods are heated by microwaves. There is considerable variation of electric field inside the microwave oven cavity. The pattern in an empty oven depends on the oven dimensions and is modified by a mode stirrer. In general; more expensive ovens tend to have a well-designed stirrer or a turntable and more uniform field distribution, while low-cost ovens have more hot and cold spots (Buffler, 1993).

When material is put into the cavity the field distribution will change compared to that of an empty oven depending on the food composition, geometry and the positioning of the food (Risman, 1992; Ohlsson and Bengtsson, 2001). The size of food product affects the depth of microwave penetration and affects the heating rate and uniformity (Heddleson and Doores, 1994). Irregular shape products are subjected to non-uniform heating due to the difference in product thickness (Mudgett, 1989). Foods with slab geometry are difficult to heat due to overheating of corners and edges.

Microwave may interact in a different way with different ingredients. So, when a microwaveable product is to be developed the fundamental mechanisms of microwave heating and the interaction of microwaves with materials should be understood.

Microwave heating occurs instantly throughout the product compared to conductive heat transfer from surface to interior in a conventional oven. Relatively large amounts of internal heating seem to result in increased moisture vapor generation inside a solid food material, which creates significant internal pressure and concentration gradients (Datta, 1990). Feng and Tang (1998) stated that moisture loss during microwave heating is enhanced due to pressure driven flow.

Microwaves offer tremendous advantages, such as time, space, energy and nutrient savings, in certain food processing operations. The disadvantage of lack of color formation observed in microwave processing does not appear when microwave is used for deep-fat frying since heat transfer by convection from the hot oil to the product is considerable.

The use of microwaves for the frying process has been studied recently and it was found that microwave frying may be considered as a new way of improving the quality of the fried potatoes. Oil absorption may be reduced in microwave frying by creating an overpressure inside the pores. Reduced oil uptake and lower acrylamide formation in potatoes was observed in microwave frying as compared to conventional deep-fat frying (Sahin et al., 2007; Oztop et al., 2007a). However, microwave fried potatoes lost more moisture as compared with the conventionally fried ones. As microwave power and frying time increased, the oil content of microwave fried potatoes also increased (Oztop et al., 2007a). The application of osmotic dehydration before frying was found to reduce the moisture and oil contents of potatoes (Oztop et al., 2007b). The effect of batter formula on qualities of microwave-fried fish nuggets has been recently studied by Chen et al. (2009). Oil contents of crust were found to be similar in both microwave and conventional frying methods. Conventional deep-fat fried crusts except the one containing 5% modified starch had higher total color changes than microwave fried crusts. They concluded that, most of the crust qualities of fish nuggets showed similarity between the two frying methods and microwave frying reduced frying time.

## 1.3 Chicken Meat

Fried chicken is one of the most popular deep fat fried foods. Chicken muscle contains 73.7% water, 20-23% protein, 4.7% lipid and 1.0% ash (Foegeding et al., 1996). Chicken muscle is largely composed of muscle protein. The most intense changes in meat during heating, such as shrinkage and toughening or release of juice and discoloration are due to changes in muscle proteins. Some moisture is bound to hydrophilic groups in muscle protein by electrostatic attraction forces, which are progressively weaker with increasing distance from the hydrophilic groups (Kropf and Bowers, 1992). At the outset of deep fat frying, as with other dehydration processes, the loosely attached moisture on the muscle surface is presumably first detached by evaporation from the wet surface (Bengtsson et al., 1976).

As frying progresses, the fibers begin to shrink in the transverse direction at 40-60°C (Offer et al., 1989). The collagen network shrinks at 60–70°C due to denaturation, significantly increasing the pressure within the bundle (Hamm, 1985; Wilding et al., 1986). Due to protein changes with heating, water content within the myofibrils in the narrow channels between the filaments changes as meat shrinks within the tissue matrix (Bertola et al., 1994), resulting in moisture loss with heating. Paths of evacuation of aqueous solutions and water vapor serve as conduits for oil intrusion (Aguilera and Stanley, 1999). Porosity also changes as a result of shrinkage during thermal processing.

## 1.4 Batter & Breading

Battered and breaded products take an important part in the frying industry. It is important that the deep-fat fried products should satisfy both health and sensory aspects of the consumer demand. The absorption of frying oil during deep-fat frying of many popular foods is of concern to the health conscious consumers. Ang (1993) stated that oil absorption may be controlled by small changes in the composition of the external layers. Since the surface properties of foods play a critical role in oil uptake during frying, batter coatings have the potential to modify the amount of fat absorbed by deep-fat fried foods (Akdeniz et al., 2005, 2006; Altunakar et al., 2004, 2006; Dogan et al., 2005a, 2005b; Mellema, 2003; Sahin et al., 2005). It may be possible to reduce oil absorption by reducing water loss from the coating (Pinthus et al., 1993). Therefore, many foods are subjected to frying after modification of the surface by a cover of bread or batter.

The aim of application of batter and/or breading in fried products is not only the reduction of oil but also serving many functions by forming a crispy and uniform layer in foods, providing enhanced visual and structural qualities as well as a tender and moist inside (Loewe, 1993; Fiszman and Salvador, 2003). Batters may also improve the nutritional value of a food product.

### 1.4.1 Batter

A batter can be defined as “a liquid mixture, basically consisting of water, flour, starch and seasonings into which food products are dipped prior to cooking”

(Suderman, 1983). Batter systems are classified into two categories: interface/adhesion and puff/tempura. The interface/adhesion batters are typically used with a supplement breading or breadcrumb. The batter serves, as an adhesive layer between the food surface and the breading and chemical leavening is not normally used. Puff/tempura batter systems are chemically leavened and used as an outside coating for the food. Tempura-type batters form a crisp, continuous, uniform layer over the food substrate, constituting its final outer coating (Loewe, 1990).

Battered foods are very complex systems since they contain a wide range of components with various characteristics. A typical batter formulation consists of wheat flour and corn flour as critical ingredients to which other flours, starches, gums, proteins, colorants and flavorings can be added as optional ingredients (Loewe, 1990). In general flour is defined as the ground endosperm of wheat however in batter systems flour is defined as the finely ground starchy material from several sources which may include corn, rice, soy or barley. The effect of different flours has been studied in fried batter systems (Shih and Daigle, 1999; Mukprasirt et al., 2000a; Dogan et al., 2005a, 2005b; Lee and Inglett, 2006). As a basis for suitable formulation of mixes, it is important to know how each of the ingredients contributes to the overall quality of the fried products. Combination of different flours may provide special effects on quality of coated products.

Wheat flour is the most common flour used in batter systems and it determines the fundamental characteristics of batter (Davis, 1983). Proximate analysis of wheat flour is given in Table 1.1.

**Table 1.1** Proximate analyses of various wheat flours (McWilliams, 1989)

| | Straight, hard wheat | Straight, soft wheat |
|---|---|---|
| Moisture, % | 12.0 | 12.0 |
| Protein(N*5.70), % | 11.8 | 9.7 |
| Fat, % | 1.2 | 1.0 |
| Ash, % | 0.46 | 0.42 |
| Carbohydrate,% | 74.5 | 76.9 |

Corn ranks as the second most widely produced cereal crop worldwide. Corn flour is made up of the ingredients obtained by the process of dry milling of yellow or white endosperm. Proximate analysis of corn flour is given in Table 1.2. Corn flour is often used to provide natural yellow color and to increase crispness in coated fried products. This is due to the diluting effect of corn on wheat gluten. It is also often added in batters to control viscosity since its higher starch level affects the batter stability to absorb water (Roger, 1990). It interacts with wheat flour in batters to affect the structure and texture of batter coatings.

**Table 1.2** Proximate analyses of corn flour (Burge, 1990)

| | Corn flour |
|---|---|
| Moisture, % | 11.0 |
| Protein(N*6.25), % | 6.5 |
| Fat, % | 1.6 |
| Fiber, % | 0.5 |
| Ash, % | 0.5 |
| Carbohydrate,% | 79.9 |

Rice flour is made from broken milled rice; therefore its chemical composition is the same as that of whole rice (Table 1.3). Rice flour exhibits properties such as the absence of gluten, low levels of sodium, protein, fat and fiber, and high amount of easily digested carbohydrates, which are desirable for certain special diets. It has also bland taste, white color, and hypoallergenic properties (Helm and Burks 1996; Yokoyama, 2004). Rice flour can be added to batters and breadings for increased adhesion and water holding capacity. Such additional water can be available for both viscosity modification at room temperature and starch gelatinization during heating. Rice flour can also aid in yielding an acceptable interface between the coating and the food substrate (Loewe, 1990). Rice flour reduces oil absorption better than wheat flour although it is less effective as a thickening agent (Mohamed et al., 1998; Shih and Daigle 1999; Dogan et al., 2005b).

The viscosities of batter systems containing corn and rice flours do not rise as rapidly as systems containing wheat flour. This could be attributed to the ability of wheat gluten to absorb water, resulting in decreased free water in the batter system

**Table 1.3** Proximate analyses of milled rice (Juliano, 1972)

| | Rice flour |
|---|---|
| Protein(N*5.95), % d.b.† | 6.5-9.6 |
| Fat, % d.b. | 0.3-1.1 |
| Fiber, % d.b. | 0.4-1.0 |
| Ash, % d.b. | 0.5-1.9 |
| Carbohydrate,% d.b. | 86.9-89.8 |

†dry basis

Legumes are important ingredients of a balanced human diet in many parts of the world, due to their high protein and starch contents. In terms of protein quantity, legumes have 2 to 3 times more protein than cereals. Additionally, legume protein fractions are poor in sulfur-containing amino acids and tryptophan; however, they are richer in lysine compared to cereals. Therefore, care must be applied to provide a good balance of amino acids in human nutrition by combination of legumes and cereals (Salunkhe et al., 1985; Swanson, 1990). Legume starches promote slow and moderate postprandial glucose and insulin responses due to poor digestibility compared to that of other cereals, and have low glycemic index values (Jenkins et al., 1980). Several properties of legumes affect starch digestibility, including high content of viscous soluble dietary fiber constituents, the presence of various antinutrients, including polyphenols and phytic acid, and relatively high amylose/amylopectin ratios (Thomson and Yoon, 1984).

Soybean is one of the most important oil and protein crops of the world. Soybean is a species of legume native to East Asia but only 45 percent of soybean production is located there. Most soy flours are prepared from defatted flakes and are the least refined of soy proteins. Proximate analysis of defatted soy flour is given in Table 1.4. The protein of soybean is called a complete protein, because it supplies adequate amount of different amino acids required for building and repairing the damaged body tissues. It contains also other biologically active components (isoflavones) that may be effective in reducing the risk of coronary heart diseases and several cancers (Trainer and Holden, 1999; Hasler, 2002). Soybean proteins have played an increasing role in human nutrition over the last two decades in both developing and industrialized countries of the world. Calcium, magnesium and potassium are the major mineral elements found in soy flour (Porter and Jones, 2003).

Soy flour was shown to bind more water as compared to wheat, corn and rice flour and this explains the higher viscosity of batter containing soy flour (Senthil et al., 2002; Dogan et al., 2005b). This increased water absorption might be partly due to higher protein content of the soy flour which contributes to a greater hydration capacity (Bahnassey and Khan, 1986).

**Table 1.4** Proximate analyses of defatted soy flour (Horan, 1967)

| | Defatted soy flour |
|---|---|
| Moisture, % | 4.5 |
| Protein(N*6.25), % | 51.0 |
| Fat, % | 1.5 |
| Fiber, % | 3.2 |
| Ash, % | 5.8 |
| Carbohydrate,% | 34 |

In many countries where wheat is not a major domestic crop, any effort made to substitute part of the wheat flour by other kinds of available flours will contribute to lowering of cost. Chickpeas, an edible legume of family Fabaceae, are highly valuable and economical source of vegetable protein that includes essential amino acids (Clemente et al., 2000). Proximate analysis of chickpea flours from different cultivars is given in Table 1.5. It is the world's third largest pulse crop in terms of area and is grown mostly in West Asia and the Mediterranean region (Clemente et al., 1998). Chickpea is rich in calcium, phosphorus, magnesium and potassium. It also contains considerable amount of ascorbic acid.

**Table 1.5** Proximate analyses of chickpea flour (Kaur and Singh, 2005)

| | Chickpea flour |
|---|---|
| Moisture, % | 6.64-8.90 |
| Protein(N*6.25), % | 20.6-26.7 |
| Crude fat, % | 0.53-1.21 |
| Crude fiber, % | 1.1-2.1 |
| Ash, % | 2.72-2.91 |
| Carbohydrate,% | 60.2-66.3 |

Flour functionality in batter and breading systems depends largely on the two major constituents of all flours, protein and starch.

#### 1.4.1.1 Flour Protein

Gelation and structure-formation are important functional properties of food proteins in many fabricated and natural food products, e.g. gelatin, egg white and comminated meat products (Kinsella, 1982; 1984).

The type and properties of gels are sensitive to many factors, including protein concentration and pH (Mulvihill and Kinsella, 1988). Gelation may occur during heating and upon cooling depending on the protein and conditions of gelation. Gel structures are responsible for many physical properties such as water-holding and rheological properties. The water holding properties of gel networks are determined mainly by the pore size distribution and a more open structure gives rise to poorer water holding than a dense network structure.

Proteins provide desirable textural attributes to foods such as foam. Foams have been described as thermodynamically unstable colloidal systems in which gas is maintained as a distinct dispersed phase in a liquid matrix (German and Phillips, 1989). Many processed food are foam type products in most of which proteins are the main surface-active agents that help in the formation and stabilization of the dispersed gas phase.

Proteins also function in color formation of foods. It was found that amino acids disappeared with reducing sugars during browning when food is heated. High protein content in flour has been associated with greater crispness and darker colour in batter fried foods (Olewnick and Kulp, 1993).

Glutenin and gliadin are the wheat proteins that are able to form a gluten network. The increase in batter viscosity during batter mixing is mainly due to gluten development. In puff/tempura batters, gluten protein retains the gas formed due to the leavening effect. The result is an aerated, porous batter, which is essential for a proper texture and crispness. In general, the tendency of gluten proteins to interact and associate with one another was found to be greater in the conditions of high protein concentration (Bushuk and Wrigley, 1971). Corn and rice flour exert a diluting effect on wheat flour gluten, increasing the available free water in the batter system (Navickis, 1987). This free water could lubricate particles; enhance flow, and results a lower viscosity value (Mukprasirt et al., 2000b). Corn and rice flours tend to feel more ‘‘gritty’’ because their proteins do not absorb water easily at lower temperatures.

The deleterious effect of nongluten protein in bread making has been attributed to a dilution effect and consequent weakening of wheat dough because of water competition between proteins, disruption of starch-protein complexes by non-gluten protein and disruption of S–S exchange for non-gluten proteins (Lorimer et al., 1991). Soy proteins were associated with wheat protein through physical interaction and covalent and noncovalent bonds during mixing and resting. These physical and chemical interactions produce large and medium-size polymers. This fact increases sodium dodecyl sulfate (SDS) solubility of insoluble gluten proteins, producing gluten depolymerization and network weakening (Ribotta et al., 2005; Perez et al., 2008).

#### 1.4.1.2 Flour Starch

Starch portion of flour along with the protein component form the structure of the final cooked batter after gelatinization during frying. For the uniform base coating, the starch portion of the batter must be evenly distributed around the substrate to ensure the formation of uniform gel, which also enriches the product in terms of flavor, smoothness and appearance. In systems such as batters where quantity of water is limited and different ingredients may be competing for it, gelatinization of starch is delayed until higher temperatures are reached. Wang et al. (2004) reported the gelatinization temperature to be affected by water and gluten contents in the dough. It is suggested that the heated gluten gel showed a greater binding of water than the starch gel in the dough. This was attributed to less water being available to starch in the presence of gluten. Addition of corn or rice flours to wheat flour exerted diluting effects on wheat gluten, increasing the amount of water available to react with wheat starch during the heating process (Xue and Ngadi, 2007). If the available water is very limited, gelatinization may not be completed and, in extreme cases, it may not occur. In conventional frying system the degree of gelatinization will be a function of water availability between the time the system reaches a temperature sufficient to begin starch gelatinization and the time that the water has vaporized and is no longer available to the starch (Davis, 1983).

Damaged starch content is found to be effective on coating characteristics. As the damaged starch level increased, due to the increase in reducing saccharide amount, which then react in Maillard reaction, the fried coatings become darker and crispier (Loewe, 1993). Damaged starch granules are also capable of absorbing higher quantities of water than intact granules (Davis, 1983).

Starch is the major constituent of milled rice and makes up 90% of milled-rice dry weight. The amylose content of rice may constitute 8 to 37% of its starch content, whereas the amylopectin is the major starch constituent (Juliano, 1972). The amylose:amylopectin ratio determines many of properties of cooked milled rice. Increasing amylose content improves the capacity of the starch granule to absorb water and expand in volume without collapsing because of the greater capacity of amylose to hydrogen bonding and retrogradation.

### 1.4.2 Breading

The word breading is a general term that refers to a large group of flour-based product, coarse in nature, and applied to moistened or battered food products prior to cooking (Suderman, 1983). A description that more clearly defines breadings as a food group classifies them as thermally processed cereal-based foods. Wheat flours that have been heat treated in a wide variety of ways do form the major type of commercially produced breadings used by broad sectors of the food industry (David, 1983).

In traditional breading, flour, reducing sugars, salt and any color are intensively blended and mixed with water in a continuous mixer to form dough, which is then forced through a series of paired rollers. This rolling action forms the dough into a sheet, which is then conveyed onto a moving band or steel belt for rapid baking then crumbled through a granulating mill or slow-speed grinder. It is then dried to final moisture content of approximately 8 %. The dried coarse particles are then roller milled, sifted and blended as required to arrive at the appropriate mesh specification.

## 1.5 Quality Parameters of Fried Chicken Fingers

Food quality is the sum of all the desirable characteristics that make a food acceptable for eating. Many factors can affect the quality of the final fried food. Fried food quality is not only related to the quality of raw materials (foods, frying oil) but also food pretreatment, food geometry, processing method and process parameters. The most important product properties that are measured and examined to determine related quality characteristics in this study are moisture content, oil content, color, texture and porosity.

### 1.5.1 Moisture and Oil Contents

The ability of processed meat and poultry products to retain moisture is a key quality characteristic. It is important to retain optimum moisture while the food is well cooked.

Demand for lower oil-content fried foods has increased with the growing health consciousness of the consumer. Therefore, oil contents of products have to be taken into consideration. Oil absorption into the product during deep-fat frying is influenced by many factors including frying temperature and time (Baumann and Escher, 1995; Krokida et al., 2000, Kassama and Ngadi, 2004) and moisture content (Gamble et al., 1987; Lamberg et al., 1990). 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 et al., 1996). In contrast, Moreira et al. (1999) argued that higher oil temperatures lead to a faster crust formation and so favoring the conditions for oil absorption. The oil uptake was found to be negatively correlated with moisture content (Sahin et al., 2000). Similar correlation was observed in microwave frying but rate of moisture loss was higher as compared to rate of oil uptake in microwave frying (Oztop, 2005). Therefore, lower oil uptake in microwave frying process was observed in potatoes as compared to conventional frying, although microwave frying resulted in high moisture loss even at low power levels. Microwave power level and frying time were found to be significant on affecting the oil content. Moreira and Barrufet (1998) reported that the tortilla chip with the lowest initial moisture content absorbs less oil. Dehydration of potatoes osmotically prior to frying reduced the oil content of fried potatoes (Oztop, 2005). In principle only the outer layer of the food needs to have low moisture content, which can also be achieved by applying a low-moisture level coating.

Oil type and quality (Blumenthal and Stier, 1991), interfacial tension (Pinthus and Saguy, 1994), pressure (Garayo and Moreira, 2002) and surface area are also the factors affecting the oil absorption. Increasing product surface area (Gamble and Rice, 1988) and lowering interfacial tension between the frying oil and coating (Maskat and Kerr, 2004) result in an increased oil uptake.

The properties of the surface of the food are most important for oil uptake. It has been shown using differential scanning calorimeter that in fried potatoes the crust layer contains six times as much oil as the core (Aguilera and Gloria, 1997). There are many options available to reduce fat uptake by application of coatings or batters. Essentially, mechanisms that enable the formation of oil-barrier films or increase the water-holding capacity may reduce oil uptake. Thus, gums (Sahin et al., 2005; Akdeniz et al., 2006), modified starches (Akdeniz et al., 2005) and proteins (Dogan et al., 2005a) have been used as additives in the preparation of reduced-oil food products. Soy protein isolate based coating was found to be one of the very promising materials for low fat fried foods within eleven different proteins and polysaccharide based edible films (Albert and Mittal, 2002). The addition of soy or rice flours to the batter formulation significantly reduced oil absorption during conventional deep frying (Shih and Daigle 1999; Dogan et al., 2005b).

### 1.5.2 Color

Color is one of the most important quality factors in deep fat fried products. The consumer generally uses the color of a product in order to determine the end of the frying process. During frying, the combination of dehydration and high temperature results in brown crust formation. The chemical browning reactions between reducing sugars and protein sources, the absorption of frying oil, density of the fried product, the temperature and frying time lead to color development during frying process (Loewe, 1993). Oztop et al. (2007a) showed that microwave power level, frying time and oil type are all significant in color development of potatoes. The increase in darkness with increasing frying temperature and time has been reported for fried food products such as potatoes (Oztop et al., 2007a) and chicken nuggets (Dogan et al., 2005b; Ngadi et al., 2007).

Ingredient composition and supplemental breading can contribute to perceived color through chemical means (denaturation of protein, gelatinization of starch and browning reaction of batter and breading system), or by physical means (granulation, absorptive capacity). Caramelization, involving thermal degradation of sugars without amine participation also takes place during frying process (Baik and Mittal, 2003). Corn flour generally produces a yellowish color due to the carotene pigment in the corn, and may be useful as a source of natural yellow color (Burge, 1990). Soy flour addition to the batter formulation was found to increase the darkness and redness of the deep fat fried chicken nuggets (Dogan et al., 2005b). Addition of chickpea flour increased the lightness while isolated soy flour decreased the lightness of biscuits (Rababah et al., 2006).

### 1.5.3 Porosity

Porosity, also referred to as voidage, is the fraction of the bulk volume of a porous medium that is occupied by pores or void spaces. Thermal processing of food causes physicochemical reactions that can affect food structure. Changes in the structure of food products play important role in the various mass transfer processes during deep-fat frying. Information on pore development in fried foods is critical to process design and accurate prediction of physical properties.

Process variables, frying oil temperature and frying time, significantly induced changes in porosity during deep-fat frying. A linear relationship was found between initial porosity (prior to frying) and oil uptake/ water removal ratio (Pinthus et al., 1995b). It is concluded that initial porosity of the product determines the final oil uptake in fried products. In addition, porosity and oil uptake increase during frying and are a function of each other (Pravisani and Calvelo, 1986; Gamble and Rice, 1987; Pinthus and Saguy, 1994; Pinthus et al., 1995b; Kassama and Ngadi, 2004, 2005). Pinthus and Saguy (1994) suggested that the intrusion of oil in voids left by evacuated moisture hinders pore development. Kassama and Ngadi (2004) showed that the final oil uptake influenced the pore development in chicken meat during deep-fat frying. Akdeniz et al. (2006) obtained more porous products with the addition of gums to the coating of deep-fat fried carrots. They suggested that the barrier property of gums to oil uptake may help to prevent filling the voids of the crust enabling more porous products. The initial moisture content also plays considerable part in pore development (Rahman, 2001; Hussain et al., 2002). Mohamed et al. (1998) reported that an increase in initial moisture content of rice flour batter led to greater pore development and oil absorption when fried as a coating for foods. Dogan et al. (2005b) found that soy flour addition to batter formulation provided higher porosity in the later stages of deep-frying of chicken nuggets compared to rice flour.

### 1.5.4 Texture

Textural quality is another important attribute for the acceptability of fried foods. It consists of a number of different physical sensations or group of physical characteristics that: (1) arise from the structural elements of the food; (2) are sensed by touching; (3) are related to the deformation, disintegration, and flow of food under force and (4) are measured objectively by functions of mass, time, and distance (Bourne, 1982). An important texture characteristic for fried products is crispness. Crispness denotes freshness and high quality (Szczesniak, 1988). A crisp food should be firm and should snap easily when deformed, emitting a crunchy sound (Christensen and Vickers, 1981). Crispness is mostly associated with low moisture foods.

The crisp final texture of the fried product can be investigated by means of instrumental or sensory techniques. Perhaps the most prevalent objective measurement for crispness is a determination via mechanical properties. The mechanical properties are associated with the structural properties of materials derived by means of the resistance to a compression of blade/probe and to a tensile that pulls the structure of food material apart by a universal testing machine such as Instron or a texture analyzer.

There are several factors affecting textural attributes of fried foods like ingredients, formula and processes (mixing and frying). The microwave power level, frying time and oil type were all found to be significant for the hardness of the potatoes (Oztop, 2005). Interactions between proteins, starch, and its components (amylose and amylopectin) are of importance for the final quality of the product (Rovedo et al., 1999).

Soy flour and rice flour added batters were found to have the same effect on hardness of the conventionally fried nuggets, whereas soy flour increased fracturability. This improvement in fracture texture development of fried products may be related to the high protein content of soy flour, which improves its film forming ability (Dogan, 2004). Blending of defatted soy flour up to the level of 40% with wheat flour increased the hardness of fried snacks (Senthil et al., 2002). Salvador et al. (2002) studied the effects of corn flour, salt and leavening on the texture of fried, battered squid rings. It was reported that the ingredient having the greatest effect on the final texture of the coating layer of the fried product is the leavening agent. Leavening agent contributes to the crispness and tenderness required for the fried outer crust of this product type.

## 1.6 Acrylamide

Acrylamide is a synthetic monomer with a wide scope of industrial applications, mainly as a precursor in the production of several polymers, such as polyacrylamide. The acrylamide monomer is toxic, while its polymer is not.

Acrylamide is classified as a probable human carcinogen by the International Agency for Research on Cancer (IARC, 1994). Exposure to acrylamide causes damage to the nervous system in humans and animals (Lopachin and Lehning, 1994; Tilson, 1981), and acrylamide is also considered a reproductive toxin (Costa et al., 1992; Dearfield et al., 1988) with mutagenic and carcinogenic properties in experimental mammalian *in vitro* and *in vivo* systems (Dearfield et al., 1995).

In 2002, industrial chemical acrylamide was found to be formed in a wide range of fried and baked foods by researchers in Swedish National Food Administration (SNFA) and University of Stockholm (Rosen and Hellenas, 2002; Tareke et al., 2002). Such findings have attracted considerable interest and wide attention. Several goverments quickly validated these findings (Ahn et al., 2002; UK FSA, 2002). Several studies have been performed by different institutes such as the Center for

Food Safety and Applied Nutrition (CFSAN) and the World Health Organization (WHO) to determine the level of acrylamide in commercially available foods. Table 1.6 shows ranges of acrylamide contents in different products.

**Table 1.6** Acrylamide content of different foods (CFSAN/FDA, 2002; Becalski et al., 2003)

| **Product** | **Acrylamide Content (ppb)** |
|---|---|
| Potato chips | 170-3700 |
| Potato chips (sweet) | 767-2762 |
| French fries (baked) | 356-1325 |
| French fries | 49-1900 |
| Breads and bakery products | ND*-364 |
| Cereals | 47-266 |
| Coffee | 175-351 |

*Not detected

There are now innumerable numbers of results reported on acrylamide in food from all over the world, either in scientific publications or on the web (Lineback et al., 2005).

Maillard browning is proposed as the most probable mechanism within several hypotheses for the development of acrylamide formation in cooked foodstuff (Mottram et al., 2002; Stadler et al., 2002; Stadler et al., 2004; Yaylayan et al., 2003; Zyzak et al., 2003). The Maillard reaction consists of the chemical reaction between reducing sugars and free amino acids (BeMiller and Whistler, 1996). The free amino acid asparagine is found to be the main precursor of acrylamide (Becalski et al., 2003; Stadler et al., 2002; Weisshaar and Gutsche, 2002; Zyzak et al., 2003). Detection of high concentrations of acrylamide is common in heated starch-rich food showing the strong relation of acrylamide formation with the sugar content, especially glucose and fructose (Amrein et al., 2003; Biedermann et al., 2002a; Biedermann-Brem et al., 2003; Rydberg et al., 2003).

Even though formation of acrylamide in foods has its dominating route through asparagine and reducing sugars, there are also other minor suggested routes for the formation, routes via below components that react with formed available amino-groups from the Maillard reaction system.

The prediction of acrylamide contents in fried foods is not a simple issue since there are many parameters acting in this complex system.

Time and temperature are the two important process parameters affecting the acrylamide formation during frying (Bråthen and Knutsen, 2005; Gertz and Klostermann, 2002; Granda and Moreira, 2005; Pedreschi et al., 2004; Pedreschi et al., 2005; Tareke et al., 2002). In some previous researches, it was indicated that the temperature was required to be higher than 120°C for the development of acrylamide (Mottram et al., 2002; Taubert et al., 2004). Some researches have found that the acrylamide content in the core is very low whereas the content at the outer layer is very high in the fried and baked products (Erdogdu et al., 2007; Gokmen et al., 2006; Surdyk et al., 2004).

The concentration of precursors and their compositions are very important factors on the formation of acrylamide. Acrylamide formation from amino acids other than asparagine was observed in model systems (Zyzak et al., 2003). Some researchers showed that addition of free amino acids (i.e. glycine, alanine, lysine, glutamine or glutamic acid), strongly reduced the acrylamide content probably by promoting competing reactions and/or covalently binding acrylamide formed (Rydberg et al., 2003; Kim et al., 2005).

Although reducing sugars are crucial participants in acrylamide formation, nonreducing sugars, such as sucrose, are found to be efficient reactants. Zyzak et al. (2003) showed that a variety of carbonyl sources could generate acrylamide from asparagine under heat, including glucose, 2-deoxyglucose, ribose, glyceraldehydes, glyoxal, and decanal. Fructose found to be more efficient in generating acrylamide from asparagine, compared to glucose (Pollien et al., 2003).

Besides the above mentioned factors, other multiple factors such as plant cultivar, farming systems, field site, fertilization, pesticide/herbicide application, time of harvest, storage time, and temperature, may all impact the final levels of the precursors to acrylamide to some degree.

Water activity, salt concentration and pH value of surface are also known to modify the reaction conditions for the acrylamide formation (Jung et al., 2003; Pedreschi et al., 2007; Rydberg et al., 2003).

Many researchers are involved in the reduction of acrylamide and various effective ways have been found. It is important to preserve the desired product quality parameters while reducing the acrylamide content.

Selection of ingredients in batter formulation is important in order to reduce acrylamide concentration in the battered and breaded products. Vattem and Shetty (2003) observed a reduction in acrylamide formation in potato chips (from 930 ppb to 580 ppb) when potato slices were coated with chickpea batter before deep-fat frying (10 min). They hypothesized that legume proteins can prevent the breakdown of the starch complex, therefore decreasing the formation of reducing sugars that accelerate the Maillard reaction and hence acrylamide formation.

The control of important processing parameters could be regarded as the most direct way to reduce acrylamide. These parameters include heating temperature and time. Vacuum frying was shown to reduce the acrylamide formation in potato chips since lower temperature is required to get the same final moisture content compared to conventional frying (Granda and Moreira, 2005). The effect of microwave frying on acrylamide content of potato strips has been studied recently and it was found that the acrylamide content of microwave fried potatoes was lower compared to those fried in conventional deep fryer because of the shorter frying time (Sahin et al., 2007).

Acrylamide may also be reduced via the addition of exogenous chemical additives, e.g. citric acid, glycine, asparaginase etc. (Pedreschi et al., 2006; Bråthen et al., 2005).

It is known that acrylamide is also degraded during processing. The acrylamide analyzed in food, is the net formation of acrylamide, that is, the result of formation and disappearance. It has been shown that prolonged heating time and higher temperature decreases the net formation of acrylamide (Rydberg et al., 2003; Biedermann et al., 2002b; Weisshar, 2004). This decrease in acrylamide content is mainly due to degradation rather than polymerization (Stadler et al., 2004).

There are a few studies in literature about the effect of microwave heating on acrylamide formation. It was demonstrated that, compared to conventional heating such as boiling or frying, microwave treatment is more favorable for the formation of acrylamide in model systems (asparagine/fructose and asparagine/glucose) and in potato chips under the same experimental conditions (treatment time and temperature) at pH 4, 8, and 10. Acrylamide content was enhanced with the increase of microwave heating power (Yuan et al., 2007). The formation of acrylamide presented a strong dependence on the heating temperature, heating time and their interactions in asparagine-sugar microwave heating systems (Zhang et al., 2008). Tareke et al. (2002) also showed that increased heating time for mashed potatoes in a microwave oven increased the amount of acrylamide. Precooking of potato strips by microwave was found to reduce the acrylamide content of French fries; however, the study did not show the advantage of microwave, since precooking was not compared with conventional methods (Erdogdu et al., 2007). Potatoes fried using 400 W microwave power for 1.0 min had 87.85% lower acrylamide content than potatoes fried conventionally for 4.5 min but a comparable moisture content (Sahin et al., 2007). However, there is no study in literature about the effects of microwave frying on acrylamide formation in battered and breaded products.

## 1.7 Microstructure of Fried Batter

Knowledge of the microstructure is important in understanding the mechanisms involved during frying of foods. Pinthus et al. (1995b) reported that oil hardly penetrates the cooked core and that the microstructure of the crust is the main determining factor in oil uptake. It is known that the main microstructural changes produced during frying includes starch gelatinization and protein denaturation (Prabhasankar et al., 2003; Llorca et al., 2001). So, different flours with variable composition of starch and protein will have different influence on microstructure and their combination may also provide special effects.

There are studies done in literature investigating the structural changes in fried foods by SEM analysis. Aguilera et al. (2001) investigated the microstructural changes in starch granules during frying. Using low temperature cryo-SEM and SEM techniques, Llorca et al. (2001) observed that consolidation of the structural elements of the batter that formed the structure of the macroscopic matrix took place during the frying of frozen battered squid. Also, microscope observations have shown that the addition of carboxymethylcellulose to the batter formula produces a microstructural matrix that favors the coating-food interaction (Llorca et al., 2005). Llorca et al. (2007) analyzed the effect of both the processing steps and the ingredients used for the formulation of the batter on the structural changes that occurred in the starch granules during the preparation of frozen battered squid. They concluded that both the processing and the ingredients used in the batter formulation influence the shape and size of the starch granules. Short thermal treatments such as pre-frying mainly affect the shape of large starch granules, which are weaker. The use of corn flour as an ingredient increases the water retention capacity of the batter, resulting in higher area values for starch granules in formulations where this ingredient is used. Scanning electron microscopy techniques were used to observe the structure of the coated and uncoated fried dough discs and it was reported that the methylcellulose coating was getting dehydrated during the frying process and remained attached to the surface of the product, explaining the lower lipid content of the coated product (Suarez et al., 2008). Naruenartwongsakul et al. (2008) used the cryo-SEM technique to study the effect of type, molecular weight, and concentration of cellulose ethers on the microstructure of fried batter-coated potatoes in two different batter systems. They found that the structure of controlled initial moisture content batters (at 134g/ 100g flour) with a higher molecular weight and concentration of methylcellulose was relatively more continuous; therefore, it might help in preventing oil penetration into the food substrate compared to controlled viscosity batter at 1200cP.

There is lack of information in literature about the effects of rice, soy and chickpea flours in batter formulations on the microstructure of battered products during conventional and microwave frying.

## 1.8 MRI Temperature Mapping

Magnetic resonance is based on the interaction between an external magnetic field and a nucleus that posses spin. Felix Bloch theorized that any spinning charged particle (like hydrogen nucleus) creates an electromagnetic field and a magnetic moment ($\mu$) is created along axis of the nuclear spin. The strength of the magnetic moment is a property of the type of nucleus. Hydrogen nuclei ($^1H$), as well as possessing the strongest magnetic moment, are in high abundance in biological material. It is very sensitive to the magnetic field due to its large value for $\mu$. Consequently hydrogen imaging is the most widely used MRI procedure. The orientation of the nuclear spin vector and how it changes due to the experimental manipulations that the nucleus undergoes provide the basis for the MR signal (Hashemi et al., 2004).

The MR experiment, in its simplest form, can be considered to be a reemission phenomenon. Energy that will be absorbed is applied to the sample. A short time later, this energy will be reemitted, detected, and processed.

Spinning nucleus in a static magnetic field will precess about the static magnetic field. The frequency at which the nucleus precesses is a function of both strength of magnetic field ($B_0$) and the particular nucleus. This angular frequency is called Larmor precession (resonance) frequency ($\omega_0$) and given by the Larmor equation:

$$\omega_0 = \gamma B_0 \tag{1.2}$$

where,

$\omega_0$ = Larmor frequency (Hz)

$\gamma$ = gyromagnetic ratio (Hz/ T)

$B_0$= strength of static magnetic field (T)

The Larmor frequency is important because it is the frequency at which the nucleus will absorb energy that will cause it to change its alignment. In proton imaging, this energy is in the radio frequency (RF) range. The electromagnetic pulse used in MRI to get signal is called as RF pulse. If the frequency of the RF pulse matches the frequency of precession of protons, $w_{0,}$ then resonance occurs. Other MR active nuclei that have aligned with $B_0$ do not resonate, because their precessional frequencies are different to that of hydrogen. The image signal rises from protons on mobile molecules, typically water and lipids. Moisture protons and fat protons simultaneously contribute to the magnetic resonance signal.

Most applications of magnetic resonance imaging (MRI) are in clinical situations. However in recent years, application of MRI to food science and technology has received increasing attention. When a process (e.g., cooling, drying, or steeping) is coupled with the MRI instrument, real-time, nondestructive, and noninterrupted testing and monitoring of the process become possible. MRI is a nondestructive, noninvasive and quick technique for mapping or imaging moisture and oil contents in foods. The internal moisture distributions were evaluated by MRI in lasagna pasta (McCarthy et al., 2002) and Japanese noodles (Kojima et al., 2001). There are also a few reports on the moisture distribution in fried-food samples such as potato cylinder

(Farkas et al., 1992), tortilla chips (Moreira et al., 1995) and coating of tempura (Horigane et al., 2003) which have been determined by MRI. MR images for oil distribution were reported for tempura type coating (Horigane et al., 2003) by the chemical shift selective (CHESS) method. Farkas et al. (1992) measured the oil-water interface in potatoes during frying using similar methods.

Magnetic resonance imaging (MRI) can also be used to map the spatial distribution of temperature inside the objects. Several methods can be used to collect temperature data for mapping heating pattern within food material. The usage of fiber optic probes (Mullin and Bows, 1993) and infrared thermal imaging (Bows and Joshi 1992; Mullin and Bows 1993; Nott et al., 1999) are common methods to measure temperature distributions. The major advantage of MRI temperature mapping is that it can be used to map complex heating patterns in three dimensions.

In microwave heating, the heating mechanism differs from conventional methods. Microwave energy heats food unevenly due to an uneven distribution of electric field. So, the temperature distribution in a food heated in a microwave field cannot be based on simple models.

MRI temperature mapping is not a new technique. It is based on the sensitivity of MR measured parameters (relaxation times, diffusion coefficient and resonance frequency) to temperature. The first method used for MRI temperature mapping was based on the longitudinal relaxation time ($T_1$) (Parker et al., 1983). Then, Le Bihan et al. (1989) have proposed an alternative method based on diffusion coefficient (D). Diffusion weighted images were used to obtain two dimensional temperature maps of a food gel sample during heating and cooling (Sun et al., 1993). The exploration of the temperature dependence of the proton resonance frequency (PRF) gained importance for imaging purposes when the idea was introduced by Ishihara et al. (1995). PRF based temperature imaging was further developed by other researchers (De Poorter et al., 1995). They used a gradient echo sequence to measure temperatures in vitro in an agarose gel and in vivo in human muscle being cooled and heated with water at 5°C and 37°C, respectively.

A typical clinical MRI scanner is tuned to the resonance frequency of water protons. This will essentially exclude the contribution from nuclei with other resonance frequencies. Because the fraction and nature of the hydrogen bonds in water vary with temperature, the screening constant is temperature dependent. The changes in screening constant cause changes to the local magnetic field experience by a nucleus according to equation 1.3. The resonance frequency of water protons also changes since it is proportional to the local value of the magnetic field (De Poorter et al., 1995).

$$B_{loc}(T) = (1 - \sigma(T))B_0 \qquad (1.3)$$

where,

$B_{loc}$= local magnetic field

$B_0$= main static magnetic field

σ= electronic shielding (screening) constant (ppm)

T= temperature

Spatial distribution of proton resonance frequencies can be observed by creating a phase-map from the real and imaginary images that are created by the MR scanners reconstruction algorithm. Temperature map is obtained by using phase map.

Comparisons between $T_1$, D and PRF-based methods have demonstrated higher precision for PRF technique (Kantt et al., 1997; Wlodarczyk et al., 1999; Nott et al., 1999). A very important advantage of the PRF method is its less dependency on the structure, and compositional features of the sample (Ishihara et al., 1995; Kantt et al., 1997). Ishihara et al. (1995) have verified that the temperature dependence of the water proton chemical shift for different tissues in vitro is almost the same as pure water. For example, the temperature dependency of chicken muscle and 4 % agar were found as 0.0114±0.0006 ppm/°C and 0.0103±0.0006 ppm/°C, respectively. This small variability means that, the same calibration coefficient may be used throughout a heterogeneous sample. Phase mapping has also been used to capture with scan times of less than 1 min the 3D heating patterns induced by microwave heating before their dissipation through thermal conduction (Nott et al., 1999). They have stated that PFR method provided the most rapid and robust protocol for mapping the three-dimensional temperature distributions induced by microwave heating of real foods when compared to other temperature-sensitive MRI parameters of water ($T_2$, $T_1$ and D). There is no study in literature investigating the heating patterns in conventionally or microwave fried foods by MRI.

## 1.9 Aim of the Study

Deep-fat frying is widely used in preparation of foods, because it imparts a desirable deep-fried flavor that is not developed during other cooking methods. Foods with fried coating possess several characteristics that are much appreciated by consumers. They are expected to have certain properties of appearance, texture and flavor that add value to the product. Coated foods have a crisp/crunchy texture with tender and juicy interior. Consumption of batters over many food categories including especially fish, seafood, poultry, cheese, vegetables, and fruits has become very popular within the last years. It is important that the deep-fat fried products should satisfy both health and sensory aspects of the consumer demand. Researchers try to find out ways to reduce oil absorption and also the acrylamide formation in fried foods.

Microwaves offer tremendous advantages, such as time and energy savings, in food processing operations. In addition, more nutritious products are formed because of shorter time in microwave processes. The studies on microwave frying are limited in literature. There is no scientific literature on functional properties of different types of flours during microwave frying. Microwave frying may be an alternative to improve the quality parameters of the chicken fingers.

The main objective of this study is to compare the microwave frying with conventional deep-fat frying in different aspects. In addition, the effects of different flours in batter on physical and chemical properties of chicken fingers will be investigated. This study is composed of mainly four parts. In the first part, the effects of using different flour types (rice, soy and chickpea flours) in batter formulations on quality parameters of microwave fried chicken fingers were determined with respect to frying time. In the second part, it was aimed to investigate the possibility of reduction of acrylamide in the coating part of chicken fingers by using microwave frying. It was also aimed to determine the effects of different flours in batter formulations on the acrylamide formation. In the third part, the influences of microwave frying and various flour types on microstructure of batter coatings were studied. In all of these studies, the effect of microwave frying was compared with conventional deep-fat frying. In the last part, two dimensional internal temperature maps of fried chicken fingers were obtained post frying using magnetic resonance imaging (MRI) and the heating patterns of chicken fingers fried in microwave oven and deep fat fryer were compared.

# CHAPTER 2

# MATERIALS AND METHODS

## 2.1 Materials

All ingredients, wheat flour & corn flour (Katmer Un San & Tic. A.Ş., Ankara, Turkey), chickpea flour (Işık Tarım Ürünleri San. & Tic. A.Ş., Izmir, Turkey), rice flour (Çapa, Istanbul, Turkey) and soy flour (Bünsa, Istanbul, Turkey) used for the experiments were supplied from the commercial markets. Sunflower oil was chosen as frying medium due to its common usage in food industry. De-boned chicken breast meat was also obtained from local market. Breading was a traditional bread crumb material made from wheat flour, hydrogenated vegetable oil, salt, preservative (potassium sorbate), color and water (Undano, Ankara, Turkey).

Acrylamide (99 %) was obtained from Sigma (Diesenhofen, Germany). Potassium hexacyanoferrate, zinc sulfate, formic acid (98 %) and acetic acid (glacial) were analytical grade and obtained from Merck (Darmstadt, Germany). HPLC gradient grade acetonitrile was obtained from J.T. Baker (Deventer, Holland). Ultra pure water was used for the chromatographic analysis (MilliQ system, Millipore, Bedford, MA, USA).

## 2.2 Sample Preparation

Chicken breast was placed in plastic bags and stored in deep-freezer at -18ºC for up to two months until used. Frozen samples were thawed at +4 ºC in the refrigerator before the experiments. Samples with a size of 7.5 cm in length, 1.7 cm in width and

1.1 cm in thickness were cut by using a manually operated cutting device. Weight of each sample was checked to have a uniform range of 12 ±1 g.

Batter formulations were composed of 2:3 (w/w) solid to water ratio. The solid content of batter formulations contained equal amounts of corn and wheat flour. Control batter formulation contained only wheat and corn flour. In the batter formulation, 1.0 g/100 g of flour mix was replaced with salt. To determine the effects of different flour types, 30 g/100 g of the corn and wheat flour mix was replaced with chickpea flour, rice flour or soy flour. In batter preparation, the dry ingredients were pre-blended and mixed with distilled water at room temperature (25 ± 1 ºC) with a hand mixer at the lowest speed (Arçelik ARK55 MS, Turkey) for 2 min.

Chicken samples were immersed individually into the prepared batter for 10 seconds and allowed to drip for 1 min. Then, the breading was applied to each battered piece.

## 2.3 Frying

Microwave frying was conducted in a domestic microwave oven (Arçelik, Istanbul, Turkey). Frying was performed using a glass container with sloping sides to prevent oil eruption. The bottom diameter of the container was 8.5 cm and the side surfaces were making an angle of 17.7° with the vertical axis. First, 750 mL oil, which was at room temperature, was heated to a temperature of 180±1$^{o}$C using 365 W (70%) microwave power level.

The power level of microwave oven was determined using IMPI 2-L test (Buffler, 1993). In this test, the oven was operated at the highest power with load of 2000 ± 5g water placed in two 1-L Pyrex beakers. Initial temperature of water was 20 ± 2$^{o}$C. Final temperatures of water were measured immediately after 2 min and 2 s of heating. The power was calculated from the following formula:

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

where m is the total mass of water in the two beakers (kg); $c_p$ is the specific heat capacity of water ($J/kg°C$), $\Delta t$ is the time of heating (s), $\Delta T_1$ and $\Delta T_2$ are the temperature rises of the water in the two beakers calculated by subtracting the initial water temperature from the final temperature.

After heating the oil, the chicken slice was immersed in hot oil and frying was performed at 365 W power level and at four different times, 0.5, 1.0, 1.5 and 2.0 minutes. Only one piece was immersed into frying oil each time. The oil was changed after 6 hours of frying time.

As a control, conventional deep frying was conducted at a temperature of $180\pm1^{o}C$ in commercial bench-top deep fryer (TEFAL, Sarcelles, France) containing 750 mL sunflower oil. Samples were fried for 1.5, 2.0 and 5.0 minutes.

Center temperature of samples and the oil temperature were recorded by insertion of a fiber optic temperature probe (FISO Technologies, Inc, Quebec, Canada) into the oil and at the center of chicken fingers during frying in both microwave and conventional deep fat fryer.

## 2.4 Analysis of Flours

### 2.4.1 Amino acid content

Concentrations of 21 kinds of free amino acids in the flours used in batter formulations were determined using LC / MS after extraction. For the extraction, 1 g of the sample was weighed into a 10 mL glass centrifuge tube with a cap. Then 500 μL of Carrez 1 solution and 500 μL of Carrez 2 solution were added. The volume was adjusted to 10 mL with 0.2 mmol $L^{-1}$ acetic acid. After vortex mixing for 2 min, the mixture was centrifuged at 2.795 × g for 10 min at −5 °C to solidify the oil. The clear supernatant was quantitatively transferred to a vial (avoiding the top oil layer if present) and filtered through a 0.45 μm nylon syringe filter prior to liquid chromatography/mass spectrometry (LC/MS) analysis. LC/MS analyses were performed in an Agilent 1100 HPLC system with a Zorbax Bonus-RP analytical column (100 mm × 2.1 mm, 3.5 μm; Agilent, Waldbronn, Germany) using an isocratic mixture of 0.01 mmol $L^{-1}$ acetic acid in a 2 $gL^{-1}$ aqueous solution of formic acid at a flow rate of 0.2 mL $min^{-1}$. Data acquisition was performed in SIM mode using the following interface parameters: drying gas ($N_2$) flow 4 L $min^{-1}$, nebuliser pressure 69.7 psi, drying gas temperature 320 °C, vaporiser temperature 320 °C, capillary voltage 3 kV, corona current 8 μA, fragmentor voltage 55 eV.

### 2.4.2 Protein Content

Protein content of the flours was determined by using Kjeldahl method (AOAC, 1995). Nitrogen conversion factors for corn flour, soy flour, chickpea flour, rice flour and wheat flour were 6.25, 6.25, 6.25, 5.95 and 5.70, respectively.

### 2.4.3 Gelatinization Properties of Flours

Gelatinization enthalpy and temperatures of flours used in batter formulations were determined using differential scanning calorimeter (Q20 DSC, TA Instrument, New Castle, DE, USA). Flour samples were weighed (1.7-3.4 mg) in hermetic aluminum pans. Distilled water was added to obtain a dry matter: water ratio of 1:2 (w/w). Sample pans were hermetically sealed and heated from 40 to 120 °C by a heating rate of 10 °C/min using an empty pan as reference. Onset, peak, conclusion temperatures and enthalpy of gelatinization (ΔH) were calculated by using instrument software.

## 2.5 Analysis of Samples

### 2.5.1 Coating Pick-up

The amount of batter and breading adhering to the samples during coating was considered as the pickup and calculated by the following equation:

$$\text{Coating pick-up (\%)} = \left( \frac{C - I}{I} \right) \times 100 \tag{2.2}$$

where,

$I$ = mass of raw chicken breast, g
$C$ = mass of battered and breaded raw chicken breast, g

### 2.5.2 Moisture Content

After separation of the coating from the chicken, moisture content of both coating and chicken parts were determined by drying in an oven (FN 500, Nüve A.Ş, Ankara, Turkey) at 105 °C up to the establishment of constant weight (AOAC, 1995).

### 2.5.3 Oil Content

Extractions were performed by a Supercritical Fluid Extraction System (SFX System 5100, ISCO Inc., Lincoln, NE, USA), which consists of an extractor (SFX 3560) and two syringe pumps (Model 100DX). 1.5 to 2.5 g of ground fried coating sample was placed into 10 ml sample cartridge. Carbon dioxide was used to extract the sample at 7900 psi and 70 °C. The flow rate was 5 mL/min. The oil content was calculated from the weight gain of the oil collected in tubes divided by weight of sample put in cartridge.

### 2.5.4 Color

Color of the fried chicken samples was measured using a Minolta color reader (CR-10, Minolta, Osaka, Japan). CIE L*, a*, b* color scale was used for color measurements. Color readings were carried out at room temperature on three different sections of each sample and the mean value was recorded. The L* value represents ‘lightness’, from zero (black) to 100 (white). The a* value represents ‘redness’ or ‘greenness’ ranging from +60 to -60 while b* value represents ‘yellowness’ or ‘blueness’ (McGuire, 1992).

The total color change *(ΔE)* was calculated from the following formula:

$$\Delta E = \left[ \left(L^* - L_0\right)^2 + (a^* - a_0)^2 + (b^* - b_0)^2 \right]^{1/2} \qquad (2.3)$$

Where, $L_0$, $a_0$ and $b_0$ are reference values belong to color of $BaSO_4$ ($L_0 = 96.9$, $a_0 = 0$, $b_0 = 7.2$)

### 2.5.5 Volume and Density

Bulk volume ($V_b$) was estimated by observing the volume of water displaced by the sample (Sahin and Sumnu, 2006). In this method, weight of the sample was recorded and then the sample was covered by paraffin to avoid water absorption into the pores. After that the covered sample was immersed into water. Because of buoyancy force, the weight of sample in water is less than its weight in air. The difference between the two weights of the sample before and after the immersion represents the buoyancy force which is equal to the weight of the displaced water. Weight of paraffin was also taken into consideration while calculating the bulk volume. Bulk volume was calculated from the formula:

$$V_b = \frac{(m_1 - m_2)}{\rho_w} \tag{2.4}$$

where,

$V_b$, bulk volume, $cm^3$

$m_1$, mass of sample in air, g

$m_2$, mass of sample in water, g

$\rho_w$, density of water, $(g/cm^3)$

Particle volume ($V_p$), which excludes the volume of air in the voids, was determined by gas displacement method (Sahin and Sumnu, 2006), with a nitrogen stereopycnometer (Quantachrome Instruments, Boynton Beach, Florida, USA). A tank pressure of 1.406 $kgf/cm^2$ was used. Particle volume is calculated by using the following formula:

$$V_p = V_2 - V_1(\frac{P_1 - P_2}{P_2}) \tag{2.5}$$

where,

$V_p$, volume of particle, $cm^3$

$V_1$, volume of the first chamber, $cm^3$

$V_2$, volume of the second chamber (sample holder), $cm^3$

$P_1$, equilibrium pressure when the second chamber is closed, $kgf/cm^2$

$P_2$, equilibrium pressure when the second chamber is open, $kgf/cm^2$

Bulk density ($\rho_b$) of the fried samples was determined from the mass ($m$) and the bulk volume ($V_b$),

$$\rho_b = m/V_b \tag{2.6}$$

The particle density ($\rho_p$) of fried samples was determined from the mass ($m$) and the particle volume ($V_P$),

$$\rho_p = m/V_p \quad (2.7)$$

Specific bulk volume ($\overline{V_b}$) was estimated from the following equation:

$$\overline{V_b} = 1/\rho_b \quad (2.8)$$

where,
$\overline{V_b}$, specific bulk volume, (cm$^3$/g)
$\rho_b$, bulk density, (g/cm$^3$)

### 2.5.6 Porosity

Porosity ($\varepsilon$), defined as the volume fraction of the air or the void fraction in the sample, was estimated from the following equation:

$$\varepsilon = 1 - (\rho_b / \rho_p) \quad (2.9)$$

where,
$\rho_b$, bulk density, (g/cm$^3$)
$\rho_p$, particle density, (g/cm$^3$)

### 2.5.7 Texture

The texture of fried coated chicken fingers was determined using Texture Analyzer TA-XT2i (with TEE32 software) (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) in compression test mode. The pre-test speed was 3.0 mm/s, the test speed was 1.0 mm/s and the post-test speed was 10.0 mm/s with 10.0 g threshold force to a distance of 5 mm. Stainless steel cylindrical probe (P/3) in 3 mm diameter and 50 kg load cell were used. The results were expressed in Newton.

### 2.5.8 Acrylamide contents of fried coatings

Stock solution of acrylamide (1.0 mg/mL) was prepared by dissolving in distilled water. The working standard solutions for the linear calibration were prepared by diluting the stock solution of acrylamide to concentration levels of 10, 25, 50, 100, 250, 500, 750, 1000 μg/L with $2\times10^{-5}$ mol/L acetic acid. Carrez I and II solutions were prepared by dissolving 15 g of potassium hexacyanoferrate and 30 g of zinc sulfate in 100 mL of water, respectively.

Coating parts of the fried chicken samples were finely ground and a 1 g portion was weighed into a 10 mL glass centrifuge tube with a cap. The extraction procedure for acrylamide analysis was the same as that used for amino acid analysis. LC/MS analyses were performed in an Agilent 1100 HPLC system consisting of a binary pump, an autosampler and a temperature-controlled column oven, coupled to an Agilent 1100MS detector equipped with an atmospheric pressure chemical ionisation (APCI) interface. Analytical separation was performed on an Inertsil ODS-3 column (250 mm× 4.6 mm, 5 μm; HiChrom, Berkshire, UK) using an isocratic mixture of 0.01 mmol $L^{-1}$ acetic acid in a 2 $gL^{-1}$ aqueous solution of formic acid (pH 2.6) at a flow rate of 0.6 mL $min^{-1}$ and a temperature of 25 °C. The LC eluent was directed to the MS system after a delay time of 6.5 min using MSD software (Agilent, Waldbronn, Germany). Data acquisition was performed in selective ion monitoring (SIM) mode using the following interface parameters: drying gas (N2, 114.7 psi) flow rate 4 L $\mathrm{min}^{-1}$, nebuliser pressure 74.7 psi, drying gas temperature 325 °C, vaporiser temperature 425 °C, capillary voltage 4 kV, corona current 4 μA, fragmentor voltage 55 eV. Ions monitored were m/z 72 and 55 for the quantification of acrylamide in the samples. Full scan analyses were performed in the mass range m/z 50–210 for the spectral identification of acrylamide and sample coextractives (Sahin et al., 2007).

### 2.5.9 Scanning Electron Microscopy (SEM) Analysis

SEM analysis was performed for different batter types before frying and for coating parts of 1.5 min microwave and 1.5 and 5.0 minutes of conventional deep-fat fried chicken samples. Batter parts of fried samples were placed in freezer at -28 °C for 1 week and then freeze dried (Christ alpha 1-2 LD plus, Osterode, Germany) for 48 hours. The freeze dried samples were immersed in n-hexane for 30 min to remove the oil prior to SEM analysis. SEM analysis was carried out using a JSM-6400 scanning electron microscope (JEOL, Tokyo, Japan). Prior to examination, samples were sputter coated with gold-palladium to render them electrically conductive by using HUMMLE VII Sputter Coating Device (Anatech Electronucs, Garfield, N.J., USA). The micrographs were taken at magnification of 1000× for batter and at magnification of 70× for the inner and outer surfaces of fried coating samples.

### 2.5.10 Magnetic Resonance Imaging (MRI) Measurements

MRI analysis was performed for samples coated with control batter deep-fried conventionally for 2 min and 5 min and using microwave for 0.5 min and 1.5 min. The 2-dimensional, multi-slice proton images (128 × 128 matrix) were obtained using a gradient echo sequence (FLASH) with a total acquisition time of 4 seconds

(TR = 33ms, TE = 3.26ms, flip angle (FA) = 20°, FOV = 4 X 4 $cm^2$ and slice thickness = 5mm). Measurements were started 1 min after removing the chicken sample from the hot oil and performed every 3 minutes over 16 minutes. The samples were positioned in the center of RF probe parallel to the magnetic field. Three axial slice images were taken through the sample in a region extending 15 mm in both directions from the center of the magnet (Figure 2.1).

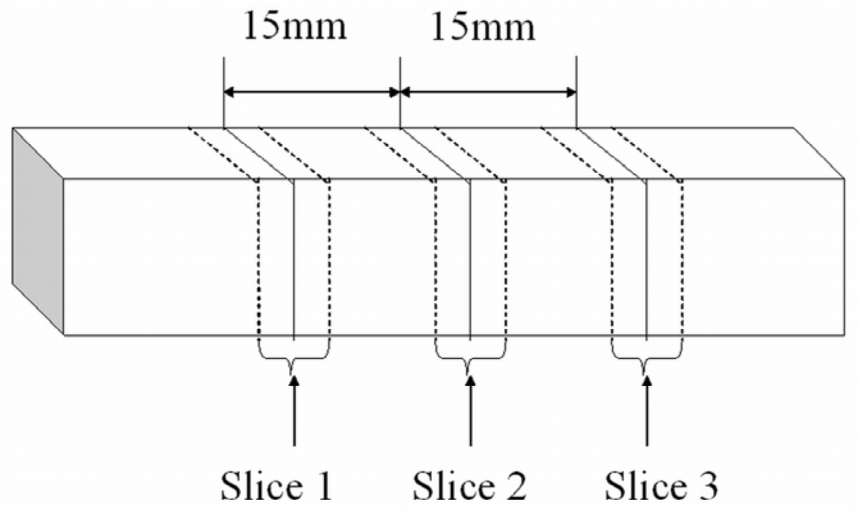

**Figure 2.1** Positions of the imaged slices within the fried chicken finger

#### 2.5.10.1 Data processing

A Bruker Biospec 7.05 T (300 MHz) imaging system at UC Davis NMR facility was used to obtain both magnitude and phase images of the fried chicken samples every 3 minutes over 16 minutes posterior to frying. The temperature difference is proportional to the phase difference of two signals. The temperature was calculated from;

$$\Delta T = \frac{\Delta\phi}{\gamma\alpha B_0 TE} \qquad (2.10)$$

where,

$\Delta T$ = temperature difference

$\Delta\phi$ = phase difference

$\alpha$= PRF change coefficient for aqueous tissue (-0.01 ppm/°C)

$\gamma$= the gyromagnetic ratio

$B_0$= the main magnetic field

$TE$ = the echo time

A MatLab (The Mathworks Inc., Natick, MA, USA) m-file was implemented for creating temperature maps of the chicken samples. The MatLab m-file calculated temperature pixel by pixel by subtracting two discrete MR phase images. One is the reference phase image at room temperature and the other is the phase image at temperature. Prior to subtraction, the MatLab script also implemented phase unwrapping. The individual phase images had phase accumulations greater than $2\pi$ resulting in phase discontinuities in both individual images and thus the resulting subtraction (temperature). Phase images were unwrapped by adding $2\pi n$ ($n$ = an integer) such that the resulting phase images used in equation (2.10) were continuous.

#### 2.5.10.2 Digital Photography

Photographs of 3 different axial slices were taken using a standard digital camera (Coolpix L6, Nikon Cor., Tokyo, Japan) at the same positions that the images were obtained for the samples.

## 2.6 Statistical Analysis

All frying experiments were performed at least in triplicate at each condition for all analysis, mean values were reported. Data obtained from the analysis were assessed by analysis of variance (ANOVA) to determine the significant differences between the effects of flour types in batter formulation and frying time on quality parameters of microwave and deep-fat fried chicken fingers. In addition, ANOVA was used to compare different frying methods. If significant difference was found, Tukey's comparison test was applied to determine the difference among means ($p \leq 0.05$) (MINITAB for Windows, Version 14).

# CHAPTER 3

# RESULTS AND DISCUSSION

## 3.1 Effects of Flour Type and Frying Method on Quality Parameters of Fried Chicken Fingers

### 3.1.1 Coating Pick-up

Pick up describes the amount of coating material adhering to the food product. It is an important factor for coated products that affects the appearance, thickness and crispness of the fried external crust (Fiszman et al., 2005). When we compare the coating pick-up values of the chicken fingers created by different flour types, it was seen that chickpea flour did not have a significant effect on coating pick-up while rice and soy flour resulted in increased pick up values (Figure 3.1 and Table A.1).

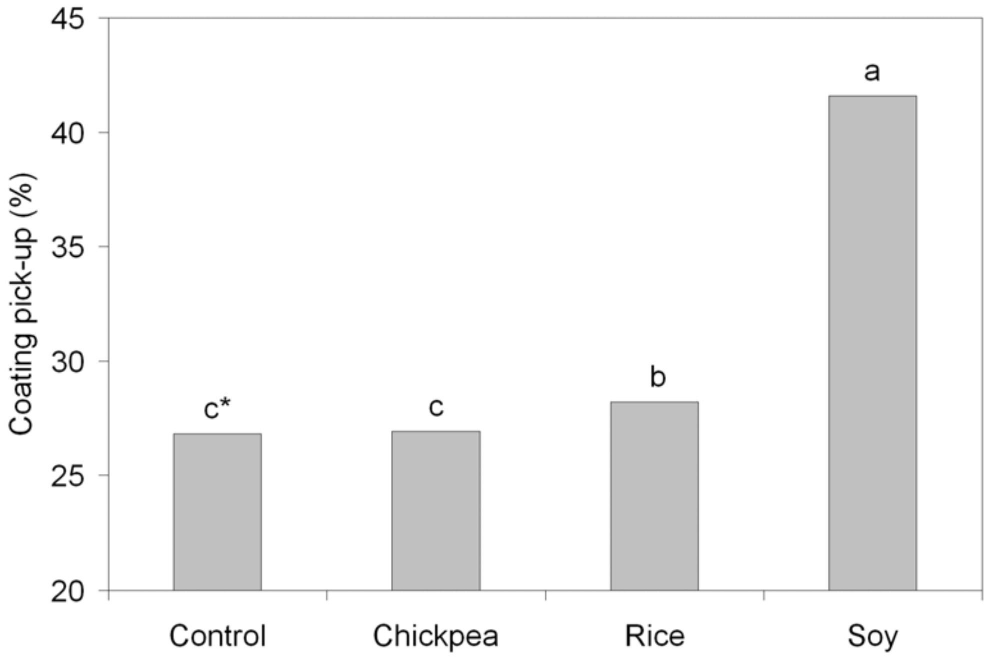

**Figure 3.1** The effect of different types of flours in batter formulations on coating pick-up of chicken fingers

* Bars with different letters (a, b, c) are significantly different (p ≤0.05)

Mukprasirt et al. (2000b) stated that the viscosity of batter applied to deep-fat fried products was critical for the characteristics of the coating, including quantity and quality of batter pickup, appearance and texture. In principle, as viscosity increases, more batter remains on the sample (Cunningham and Tiede, 1981; Salvador et al., 2002; Dogan et al., 2005a, 2005b).

The highest coating pick-up observed in the case of soy flour added batter may be related to higher viscosity and higher water binding capacity of soy flour (Dogan et al., 2005b). Greater hydration capacity of soy flour may be due to its higher protein content (Senthil et al., 2002). Approximately 70–80% of soy proteins are water soluble, whereas gluten is water insoluble (McWatters, 1978; Senthil et al. 2002). Dogan (2004) showed that soy flour added batter was found to have higher viscosity and pick-up values as compared to rice flour added one.

Although rice flour is known to be a poor thickening agent as compared to corn flour (Kohlwey et al., 1995) and wheat flour (Shih and Daigle, 1999), rice flour added coating had a higher pick up value as compared to control. This may be related to the ratio of damaged starch granules which absorbs higher amounts of water (Loewe, 1993). Mukprasirt et al. (2000b) used rice flour containing about 3 times as much damaged starch as corn flour in rice based batter and obtained a higher consistency coefficient when the rice level was increased in the batter formulation.

Chickpea flour addition did not have a significant effect on pick-up. Decreased water absorption capacity of chickpea flour added composite flour may be a reason for this. Singh et al. (1991) studied on the improvement of functional properties of wheat-chickpea flour blends. They showed that farinograph water absorption and dough stability decreased significantly above the 20% level of chickpea flour addition.

### 3.1.2 Moisture Content

Moisture content in coating layer of fried chicken finger decreased significantly with increasing frying time during microwave frying (Figure 3.2). Tukey-test showed that presence of chickpea flour or rice flour in the batter formulation had the same effect on moisture retention with control, but the presence of soy flour caused significantly higher moisture content (Table A.2). The greater hydration capacity of soy flour may be ascribed to its higher protein content (Table 3.1). When chickpea or rice flours were used in batter formulation, similar moisture content with control, 21-22%, was obtained after 1.5 min microwave frying time (Table A.3). The moisture content of coating material prepared with soy flour reached nearly 23% after 2.0 min microwave frying time (Figure 3.2).

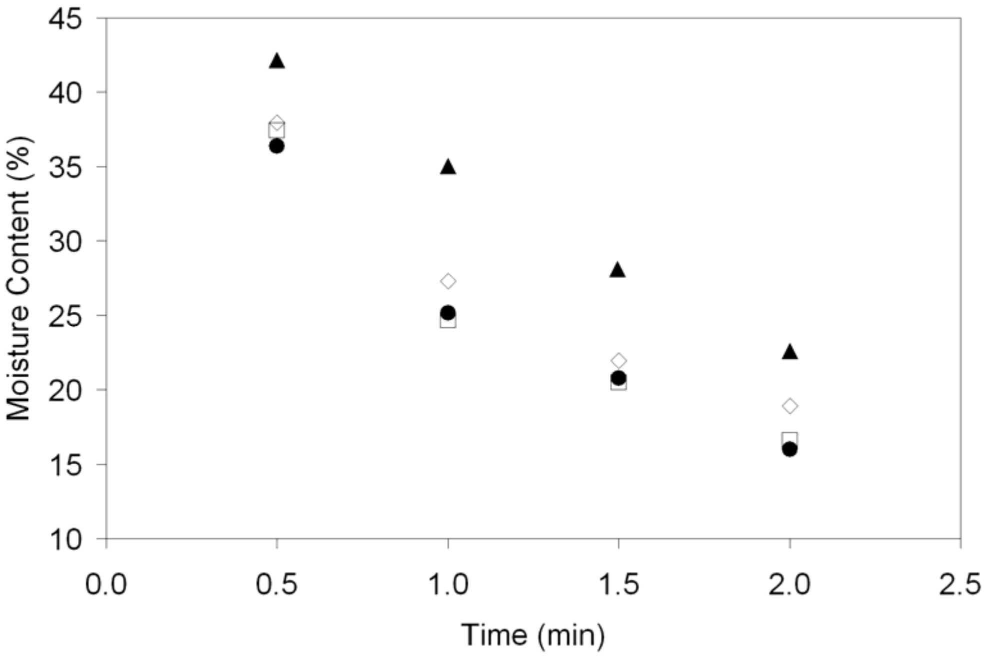

**Figure 3.2** Variation of moisture content in the coating part of chicken fingers having different flours in its batter formulation during microwave frying

(□) control[b], (◊) chickpea flour[b], (●) rice flour[b], (▲) soy flour[a]

* Flour types with different letters (a, b, c) are significantly different ($p \leq 0.05$)

**Table 3.1** Protein contents of different flour types

| Flour Type | Protein (g/100 g) |
|---|---|
| Soy | 56.82 ± 1.580 |
| Chickpea | 22.32 ± 0.450 |
| Rice | 3.33 ± 0.180 |
| Wheat | 9.58 ± 0.250 |
| Corn | 5.43 ± 0.330 |

For conventionally fried samples, only the addition of soy flour to batter formulation significantly increased the moisture retention of coating compared to control as in the case of microwave frying (Figure 3.3 and Table A.4).

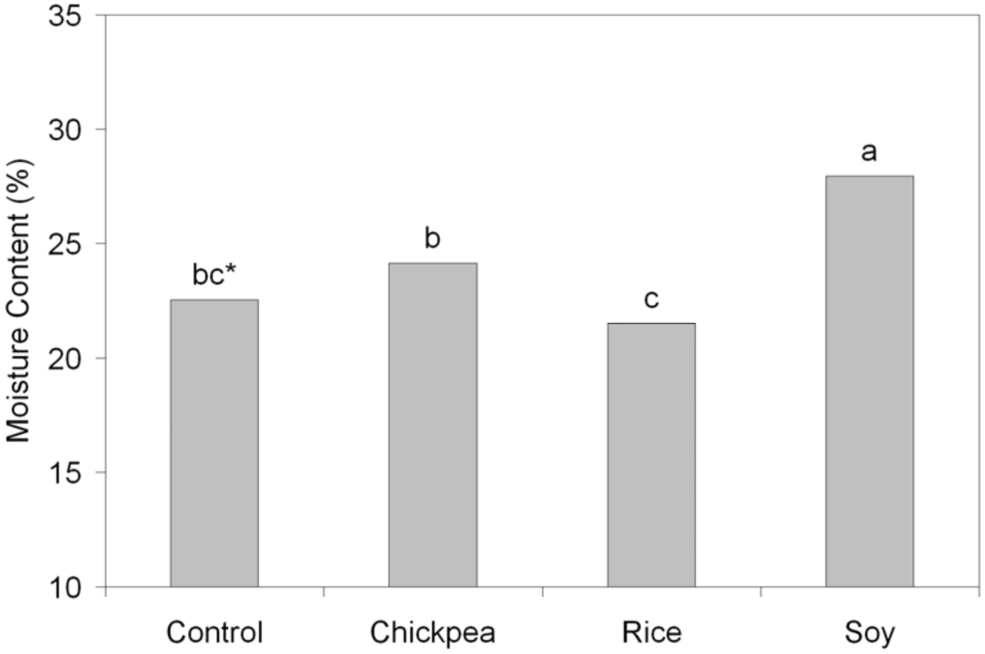

**Figure 3.3** The effect of different types of flours in batter formulations on moisture content of coating part of deep-fat fried chicken fingers for 5 min

* Bars with different letters (a, b, c) are significantly different ($p \leq 0.05$)

Moisture content in chicken part of fried chicken finger also decreased significantly with increasing frying time during microwave frying for all samples (Figure 3.4). Addition of chickpea or soy flour to batter formulation significantly increased the moisture retention of chicken part of fingers compared to control during microwave frying (Figure 3.4 and Table A.5). Similar trend was observed in the case of conventional frying for 5.0 min (Figure 3.5 and Table A.6). At 1.5 min of microwave frying time, only the soy flour resulted higher moisture content in the chicken part compared to control (Table A.7).

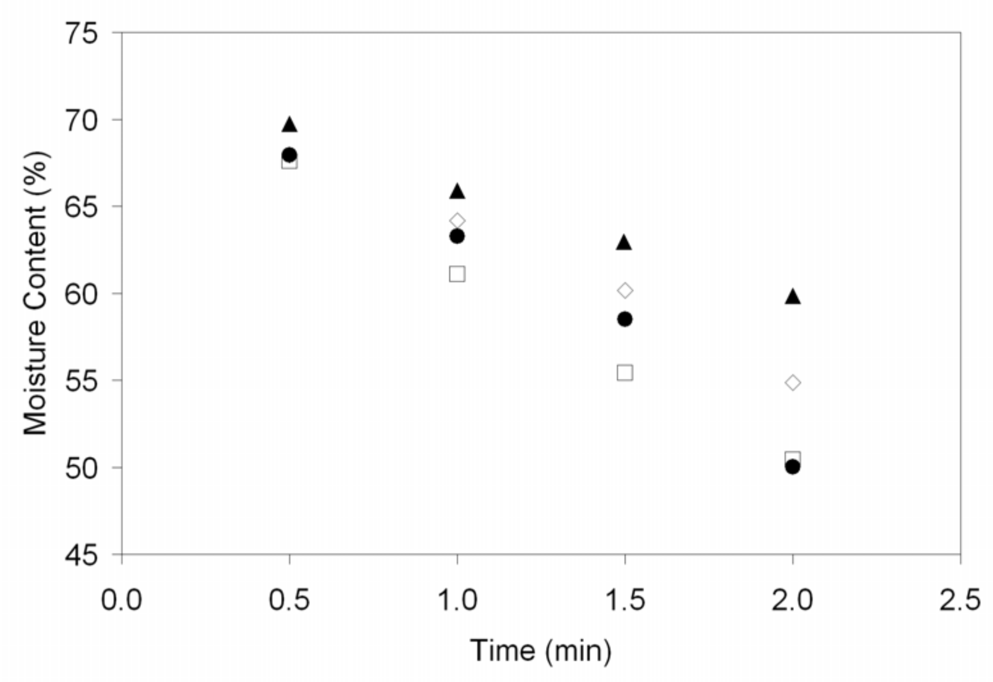

**Figure 3.4** Variation of moisture content in the chicken part of chicken fingers having different flours in its batter formulation during microwave frying
(□) control[c], (◊) chickpea flour[b], (●) rice flour[bc], (▲) soy flour[a]

Samples fried for 1.5 min in microwave oven and 5 min in conventional deep frying were acceptable for consumption. When the moisture contents of the samples fried at these conditions were compared, it was found that the frying method did not have a significant effect on moisture content of coating (Table A.8) but have significant effect on moisture content of chicken part (Table A.9). Chicken parts of fingers fried in microwave oven had lower moisture content values compared to the ones fried in conventional deep-fryer at these frying times. The moisture loss values in the chicken part of 1.5 min microwave fried and 5 min conventionally fried control samples were 24.6% and 15.7%, respectively. It can be said that using microwaves as a frying method decreased frying time significantly, but increased moisture loss as compared to conventional frying. This result is consistent with that found by Oztop et al. (2007a). The moisture content of potatoes fried in microwave oven at 400 W power level for 3 min were lower (52.89 %), as compared to those fried conventionally for

4.5 min (67.44%). This may be due to the development of relatively higher internal pressure during microwave heating. For a high moisture material like chicken muscle, rapid development of this high pressure pushes the moisture towards the surface where it is evaporated from the surface.

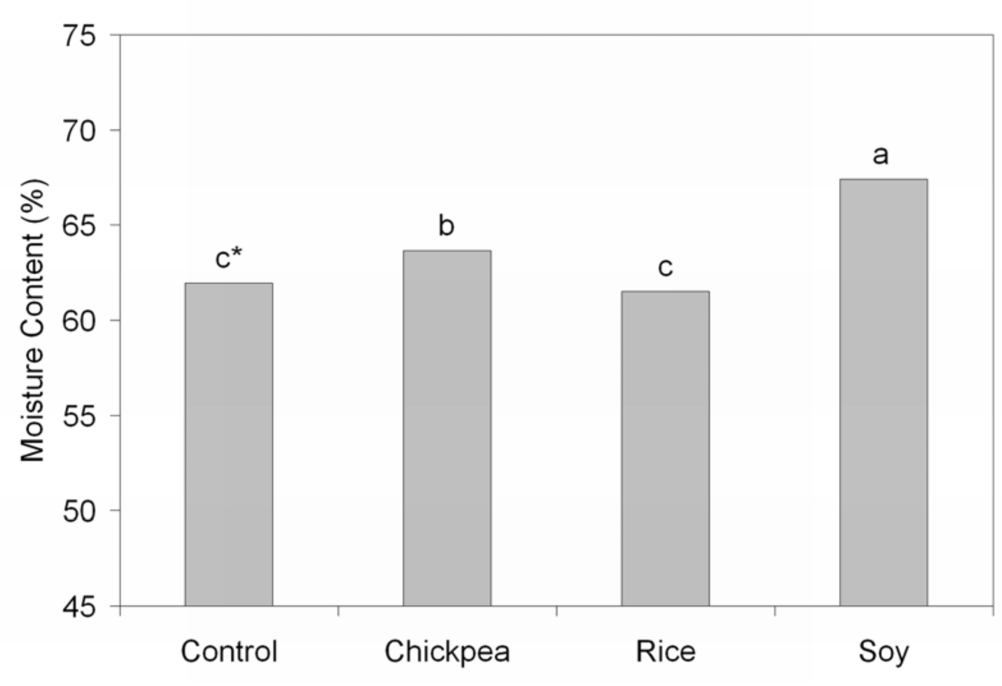

**Figure 3.5** The effect of different types of flours in batter formulations on moisture content of chicken part of deep-fat fried chicken fingers for 5.0 min

* Bars with different letters (a, b, c) are significantly different ($p \leq 0.05$)

### 3.1.3 Oil Content

Oil contents of coating parts of chicken fingers during microwave frying were represented in Figure 3.6. Frying time did not have a significant effect on oil content (Table A.10). The addition of chickpea and rice flour showed similar oil absorption during microwave frying when compared with control (Table A.10). This is an expected result since variation of moisture contents when these flours were used, were also similar (Figure 3.2). According to Tukey test results (Table A.10), soy flour provided significantly lower oil uptake compared to others during microwave frying. Due to its higher water binding capacity, soy flour added batter can control moisture loss and so the oil uptake during frying. Dogan et al. (2005b) and Senthil et al. (2002) also observed that addition of soy flour reduced oil contents of fried products.

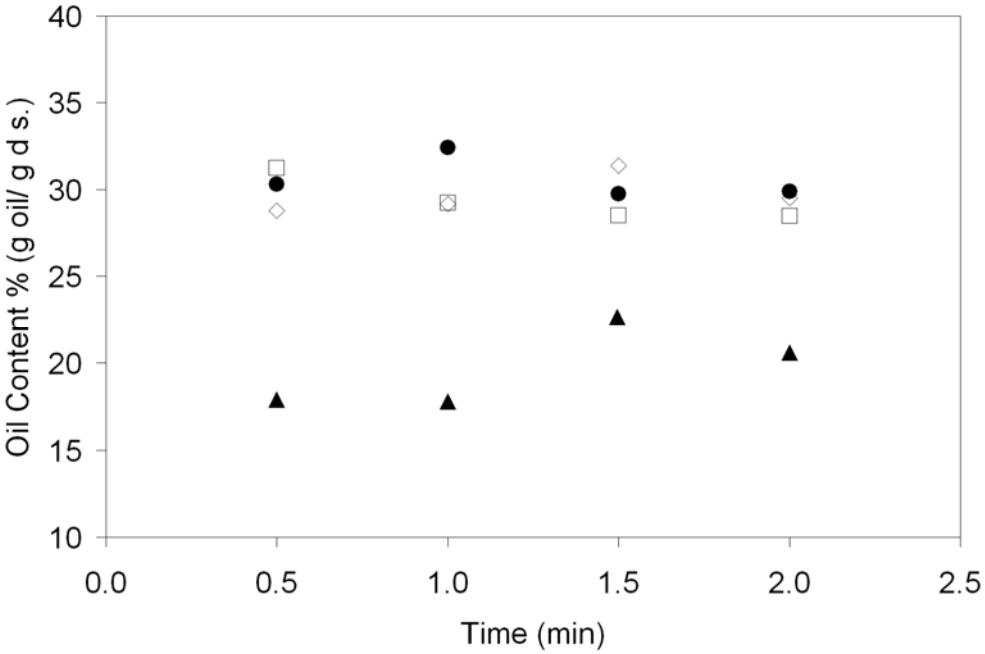

**Figure 3.6** Variation of oil content in the coating part of chicken fingers having different flours in its batter formulation during microwave frying
(□) control[a], (◊) chickpea flour[a], (●) rice flour[a], (▲) soy flour[b]

It was shown in a previous study that, oil content of the potatoes increased with increasing microwave frying time (Oztop et al., 2007a). However, in this study the data seems to be erratic. The short time period that the oil absorption data was obtained may be a reason. Kassama and Ngadi (2005), in their study, obtained similar result for the first 45 sec of deep frying of chicken. They concluded that oil uptake in this short lapse of time is mainly due to surface adhesion, penetration likely being inhibited by the movement of water at the surface layer. It is also known that most of the oil uptake is during cooling (Gamble et al., 1987). At 1.5 min of microwave frying time, soy flour provided the lowest oil uptake in the coating part and chickpea flour resulted in increased oil absorption as compared to control (Table A.11). This may be related to the difference in porosities of chicken fingers prepared using these flours. The porosity of the product formed during frying is known to play an important role in the subsequent oil uptake (Pinthus et al., 1995a, 1995b; Kassama and Ngadi, 2004). For conventionally fried samples also, soy flour added coating had lower oil content compared to chickpea and rice flour added ones (Figure 3.7 and Table A.12).

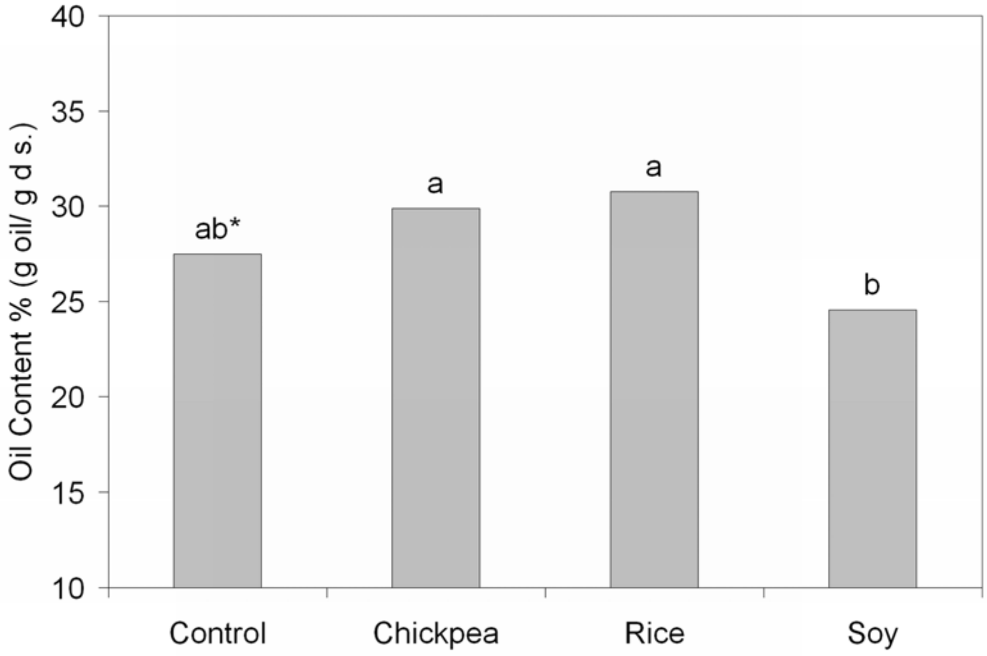

**Figure 3.7** The effect of different types of flours in batter formulations on oil content of coating part of deep-fat fried chicken fingers

* Bars with different letters (a, b, c) are significantly different ($p \leq 0.05$)

When oil contents of 1.5 min microwave fried samples were compared with that of conventionally fried ones for 5 min, frying method was found to be insignificant on affecting oil content (Table A.13). In a previous study, it was found that microwave fried potatoes had lower oil contents compared to conventionally fried ones (Oztop et al., 2007a). The short frying time and high evaporation rate of water compared to diffusion of oil into the potato due to pressure driven force that is generated by microwaves were suggested as possible reasons for this. However, higher moisture loss in microwave frying may also result higher oil absorption as compared to conventional deep-fat frying. There is a trade off between the high moisture loss and short frying time. Chen et al. (2009) showed that the microwave fried crusts of fish nuggets did not have lower oil content compared to the conventional deep-fat fried ones, although frying time for microwave frying was shorter than that for conventional frying. Diffusion of oil into the product may be limited by high evaporation rate of water during frying; however, it is still not clear how and when the oil is adsorbed by the product. Ufheil and Escher (1996) concluded that oil uptake is primarily a surface phenomena involving an equilibrium between adhesion and drainage of oil during the cooling period. Gamble et al. (1987) suggested that most of the oil enters the surface at damaged areas during cooling. Also, Moreira et al. (1997) observed that only 36 % of the final oil content was absorbed by the tortilla chips during frying and 64 % during cooling. The surface properties of food are very important for oil uptake.

### 3.1.4 Color

The crust color of fried products affects consumers' purchasing. The effect of flour types on color of microwave fried chicken fingers was shown in terms of CIE L*, a* and b* values (Figure 3.8-Figure 3.10). As expected, an increase in frying time resulted in significant changes ($P<0.05$) in crust color (Table A.14 - Table A.16). Reduction in L* values and increase in a* values with increasing frying time for all coating types showed that the chicken became darker and got more red, respectively (Figure 3.8 and Figure 3.9). In general the color changes are confirmed by an increase in parameter a* and the reduction of L* during conventional deep frying (Innawong et al., 2006; Dogan et al., 2005b) and also microwave frying (Oztop et al., 2007a). There were no significant difference between L* and a* values of the different coatings and control except soy flour added coating which provided higher L* and lower a* values compared to control during microwave frying (Table A.14 and Table A.15) and also at 1.5 min of microwave frying time (Table A.17 and Table A.18).

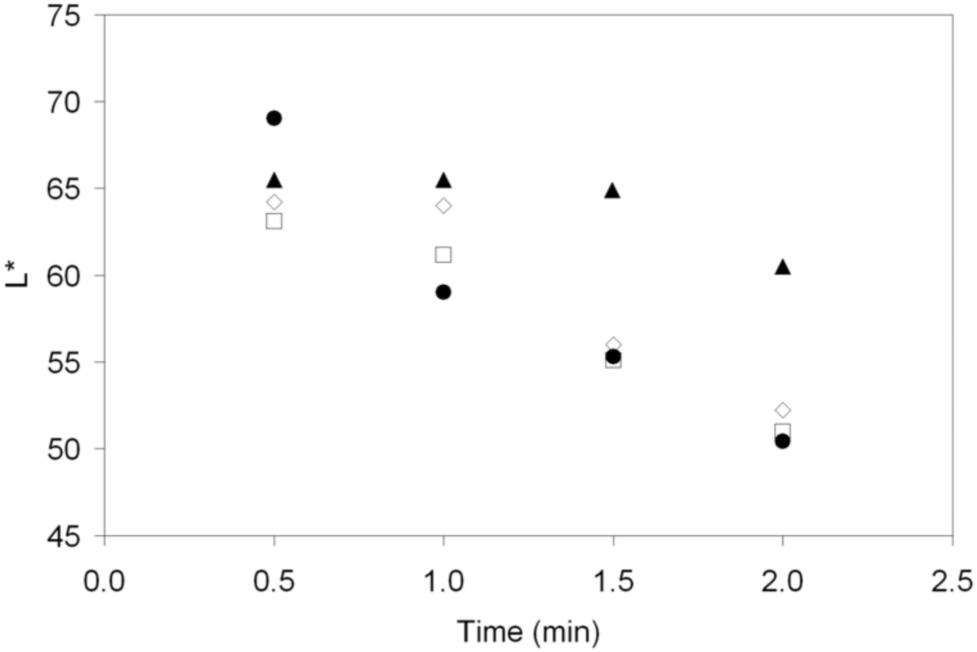

**Figure 3.8** Variation of L* values in the chicken finger having different flours in its batter formulation during microwave frying
(□) control$^{b}$, (◊) chickpea flour$^{ab}$, (●) rice flour$^{ab}$, (▲) soy flour$^{a}$

In literature it was reported that high protein content in flour has been associated with batter-fried foods with darker colour (Olewnik and Kulp, 1993). Dogan et al. (2005b) showed that soy flour addition to batter formulation increased the darkness and redness of the chicken nuggets. However, the percentage of soy flour in batter mixture was very low (5%) compared to this study. Akdeniz et al. (2006) reported that color changes during frying of carrots coated with different gums were significantly less than the ones coated with control batter. They suggested that the ability of gums to bind moisture prevents dehydration and inhibits the Maillard browning reaction. Therefore, although soy flour contains the highest amount of protein (Table 3.1), Maillard reaction may take place in a lower rate due to the higher moisture retention ability of soy flour.

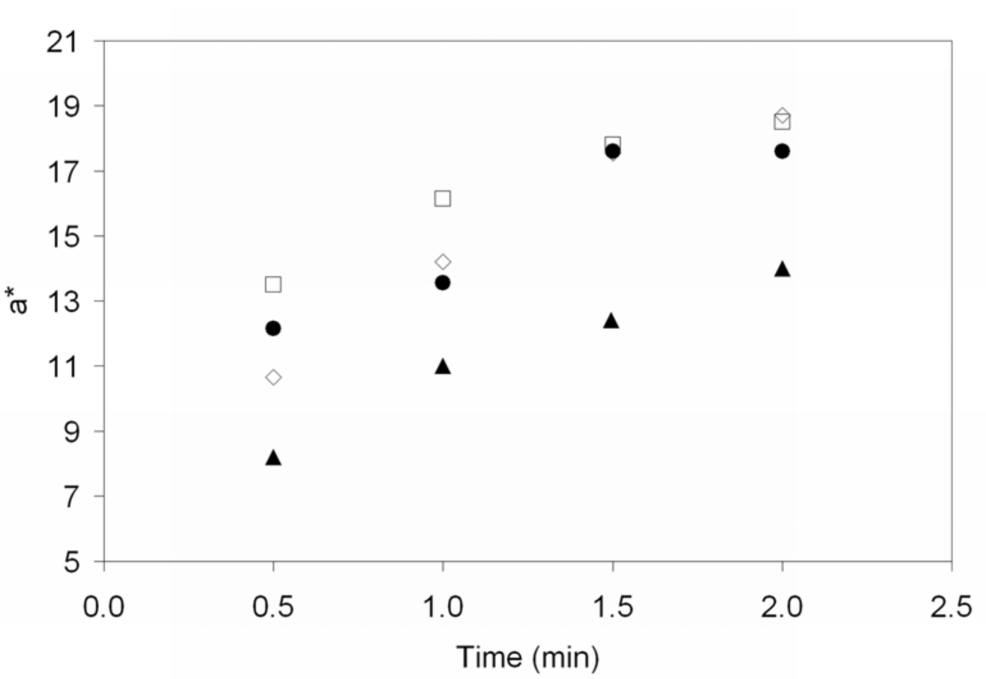

**Figure 3.9** Variation of a* values in the chicken finger having different flours in its batter formulation during microwave frying
(□) control[a], (◊) chickpea flour[a], (●) rice flour[a], (▲) soy flour[b]

In Figure 3.10, b* values of microwave fried chicken fingers were represented. There was a significant reduction in b* values with increasing microwave frying time, however, no significant difference was observed between the coating types (Table A.16).

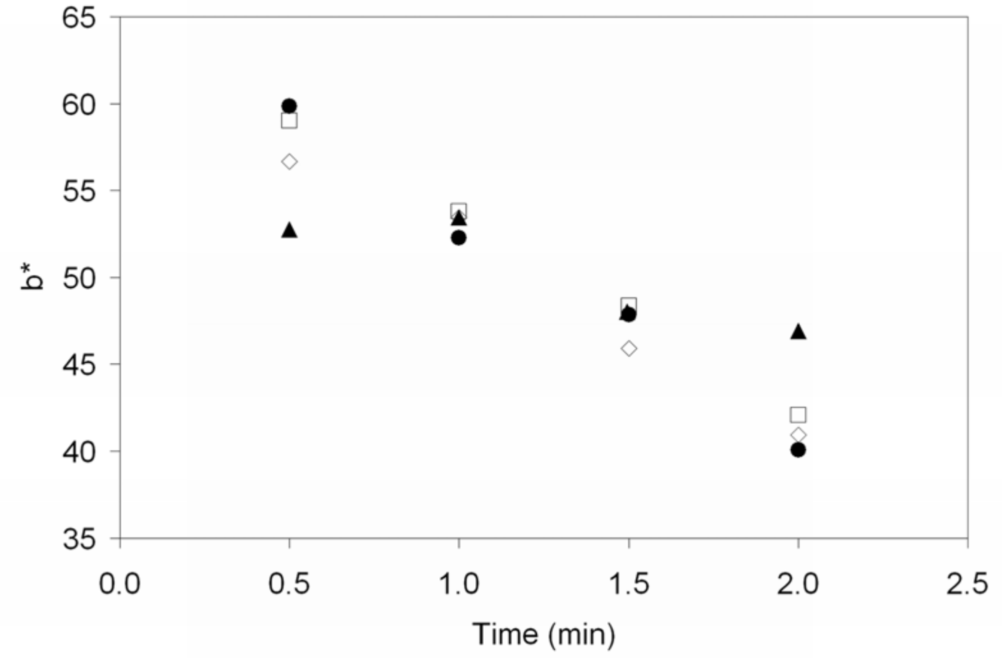

**Figure 3.10** Variation of b* values in the chicken finger having different flours in its batter formulation during microwave frying
(□) control[a], (◊) chickpea flour[a], (●) rice flour[a], (▲) soy flour[a]

For conventionally fried samples, all flour types in batter formulation provided similar L*, a* and b* values (Table 3.2). Control samples had lower L* and b* values and similar a* values as compared to other coating types (Table A.19-Table A.21).

**Table 3.2** Effects of addition of different flour types on color values of conventionally deep fat-fried chicken fingers

| Flour type | L* | a* | b* |
|---|---|---|---|
| Control | 46.4 ± 0.850 $^b$ | 17.7 ± 0.400 $^a$ | 36.7 ± 0.400 $^b$ |
| Chickpea | 50.5 ± 0.650 $^a$ | 17.4 ± 0.250 $^a$ | 39.7 ± 0.300 $^a$ |
| Rice | 49.9 ± 0.600 $^a$ | 18.6 ± 0.150 $^a$ | 39.2 ± 0.550 $^a$ |
| Soy | 51.8 ± 0.100 $^a$ | 17.3 ± 0.050 $^a$ | 39.1 ± 0.000 $^a$ |

Color parameters with different letters (a, b, c) are significantly different ($p \leq 0.05$)

If the samples fried for 1.5 min in microwave oven and 5 min in conventional deep frying which were acceptable for consumption were compared, it was seen that frying method was significantly effective on L* and b* values but not on a* values (Table A.22-Table A.24). The conventionally fried samples had lower L* values, meaning darker in color, compared to microwave fried ones (Table 3.2 and Figure 3.8). Lower b* values were also obtained with conventionally fried samples. Color changes were correlated with frying temperature and frying time in many studies in literature (Velez-Ruiz and Sosa-Morales, 2003; Dogan et al., 2005b; Innawong et al., 2006; Ngadi et al., 2007). Frying time was shorter in the case of microwave frying and this may be a reason for obtaining the lighter colored samples.

### 3.1.5 Specific Bulk Volume

Specific bulk volumes of the microwave fried samples increased with increasing frying time and flour types were found to be not significantly effective on specific bulk volume (Figure 3.11 and Table A.25).

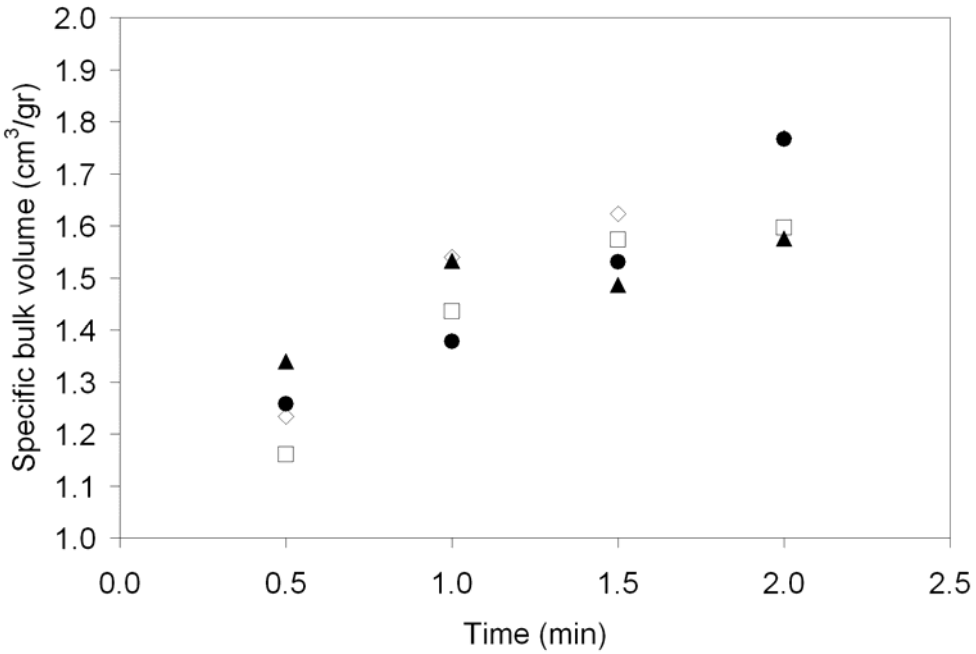

**Figure 3.11** Variation of specific bulk volumes of chicken finger having different flours in its batter formulation during microwave frying
(□) control[a], (◊) chickpea flour[a], (●) rice flour[a], (▲) soy flour[a]

At 1.5 min of frying time, microwave fried samples had significantly higher specific bulk volume values as compared to conventionally fried samples (Figure 3.12). Higher specific bulk volume values of microwave fried samples can be explained by the development of relatively higher internal pressure during microwave heating. Specific bulk volume values of microwave and conventionally fried samples at 1.5 min of frying time were found to be higher for control and chickpea flour containing batters as compared to others (Figure 3.12). This may be explained by the difference in film forming abilities of different proteins. Control formulation has higher amount of wheat flour. It is known that gluten protein retains gas which results in higher specific bulk volume. Higher specific bulk volume of chicken fingers prepared with chickpea flour may be due to its high protein content. Although soy flour also contains high protein, bulk volume of chicken fingers with soy flour was lower than control samples and samples with chickpea flour. This may be explained by high viscosity of soy flour containing batter may which may prevent expansion.

Increasing conventional frying time to 5 min increased the specific bulk volume values of samples (Figure 3.12).

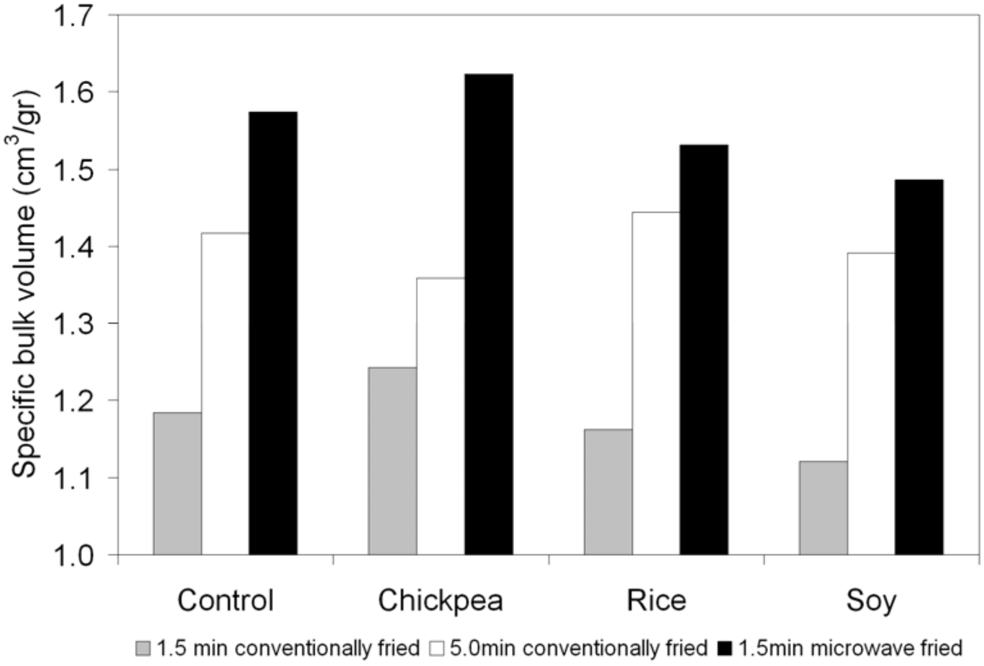

**Figure 3.12** The effect of different types of flours in batter formulations on specific bulk volume of fried chicken fingers

### 3.1.6 Porosity

Porosity of the microwave fried samples increased with increasing frying time and flour types were found to be not significantly effective on porosity (Figure 3.13 and Table A.26). The increase in pore development is associated with increased moisture loss (Kassama and Ngadi, 2003, 2004). The trend was not similar for all batter formulations. For the samples coated with control and soy flour added batter, porosity tends to level off at higher frying times. Similar results were also observed by other researchers during conventional deep frying (Dogan et al., 2005b; Kassama and Ngadi, 2003). The absorbed oil may hinder the pore development. However, the mechanistic relation between uptake and porosity is not totally clear. Difference in film forming capabilities of different batters will also affect the porosity and accordingly the oil uptake mechanisms of samples. Akdeniz et al. (2006) stated that the barrier property of gums to oil uptake may help to prevent filling the voids of the crust enabling more porous products.

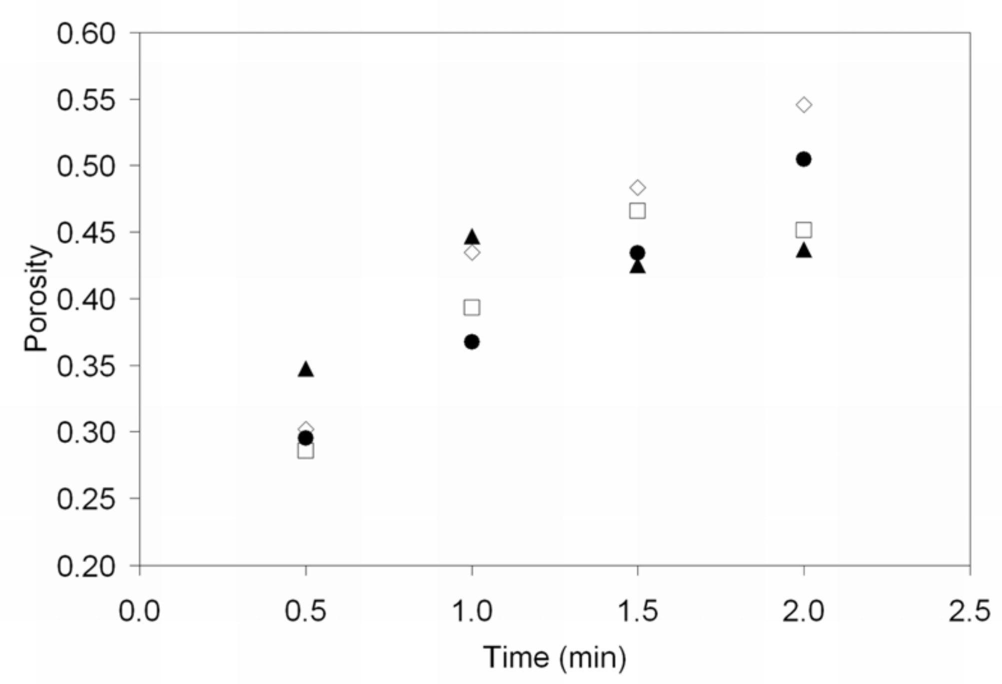

**Figure 3.13** Variation of porosity of chicken finger having different flours in its batter formulation during microwave frying
(□) control[a], (◊) chickpea flour[a], (●) rice flour[a], (▲) soy flour[a]

As expected, increasing time increased the porosity values of samples in conventional deep-fat frying also (Figure 3.14). For 1.5 min of microwave and conventional deep frying time, higher porosity values were obtained with the sample containing chickpea flour in its batter formulation compared to the ones with rice and soy flour. Higher porosity of chickpea flour containing batter resulted in higher oil uptake (Figure 3.6). Pinthus et al. (1995b) stated that porosity and oil uptake are dependent on each other; the increase in porosity caused a higher oil uptake. Porosity values of 1.5 min microwave fried samples were higher as compared to 1.5 and 5.0 min conventionally fried ones (Figure 3.14). This may be due to the development of relatively higher internal pressure during microwave heating.

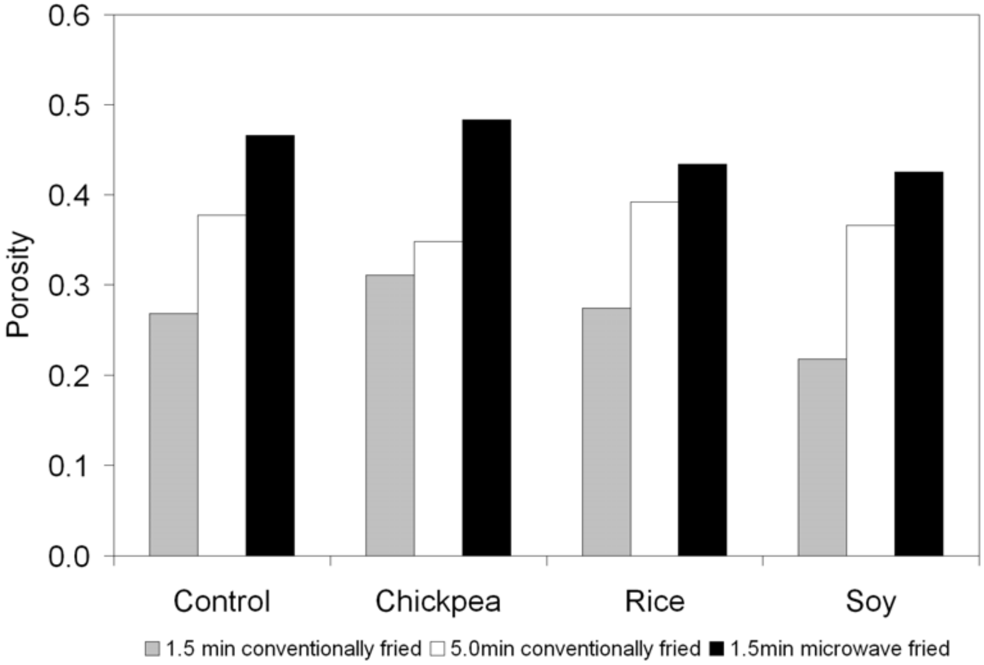

**Figure 3.14** The effect of different types of flours in batter formulations on porosity of fried chicken fingers

### 3.1.7 Texture

The effect of different flour types on hardness of microwave fried chicken fingers were shown in Figure 3.15. All flour types resulted in lower hardness values as compared to control. The lowest value of hardness was obtained with chickpea flour added batter during microwave frying (Table A.27) and also at 1.5 min of microwave frying time (Table A.28). This may be related with the higher porosity of samples having chickpea flour in its batter formulation at this frying time (Figure 3.14).

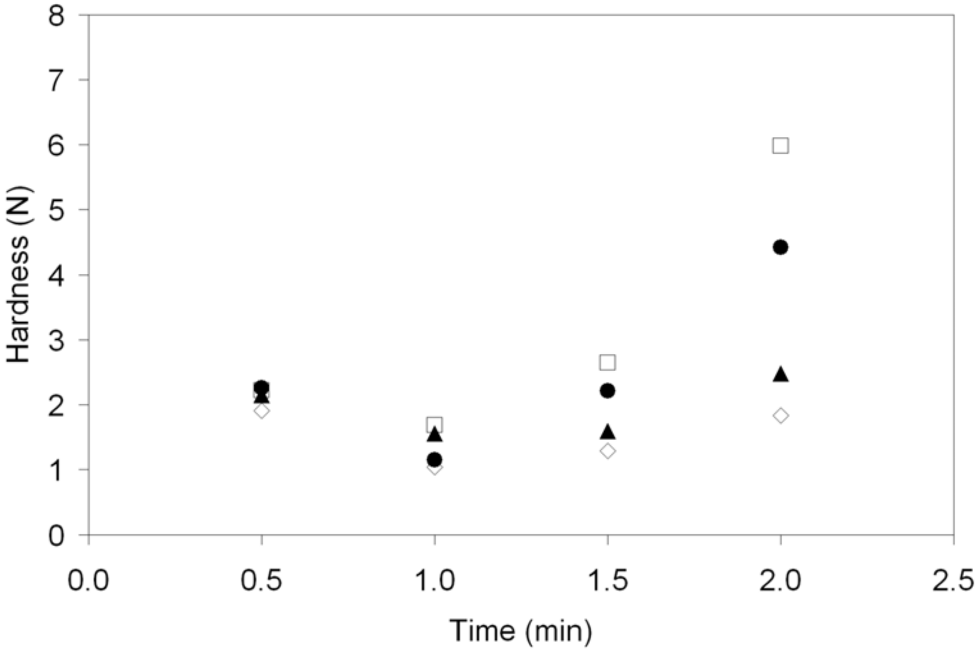

**Figure 3.15** Variation of hardness of chicken finger having different flours in its batter formulation during microwave frying
(□) control[a], (◊) chickpea flour[c], (●) rice flour[b], (▲) soy flour[b]

Rice and soy flour had the same effect on hardness of the microwave fried fingers. This was also observed by other researchers for conventionally fried nuggets (Dogan, 2004). Lower hardness value obtained with soy flour added coating may be related with its higher pick-up value compared to others. Rice flour containing batter had also higher pick-up value as compared to control. Suderman (1983) reported that thicker coatings made from a mixture of waxy rice flour and corn flour are very smooth and lack in texture. By contrast, a thinner, less viscous coating from these same ingredients will allow air bubbles to appear on the surface and result in more appealing texture.

Hardness values for deep fried samples for 5 min were given in Figure 3.16. Control sample had the highest hardness value as in the case of microwave frying (Table A.29). Corn flour is known to increase crispness of coated product (Roger, 1990). Interactions between proteins, starch, and its components (amylose and amylopectin) are of importance for the final quality of the product (Rovedo et al., 1999).

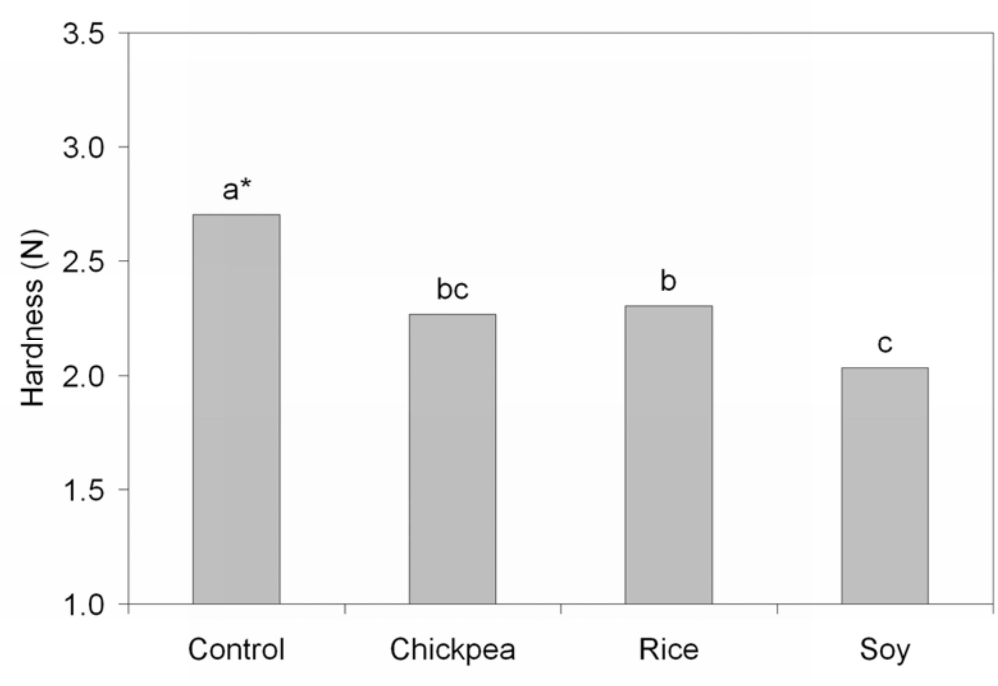

**Figure 3.16** The effect of different types of flours in batter formulations on hardness of deep-fat fried chicken fingers

* Bars with different letters (a, b, c) are significantly different ($p \leq 0.05$)

When the samples fried for 1.5 min in microwave oven and 5 min in conventional deep frying were compared, microwave fried samples had lower hardness values than conventionally fried ones (Table A.30). This may be caused from the higher porosity values obtained during microwave frying (Figure 3.14).

## 3.2 Effects of Flour Type and Frying Method on Acrylamide Formation in Coating Part of Chicken Fingers

Figure 3.17 shows the formation of acrylamide in coating parts of chicken finger during microwave frying for different types of flours. The trend for the change of acrylamide content of rice flour added coating was very close to that of the control throughout frying. For these coating types, acrylamide concentration reached a plateau after increasing for a certain period of time. This may be due to the depletion of reactants for acrylamide formation in these batters since the asparagine content of the rice, wheat and corn flours is lower than that in the soy and chickpea flours (Table 3.3). In addition, it was suggested that the acrylamide is not only forming, but also degrading at prolonged heating times (Granda and Moreira, 2005; Taubert et al., 2004).

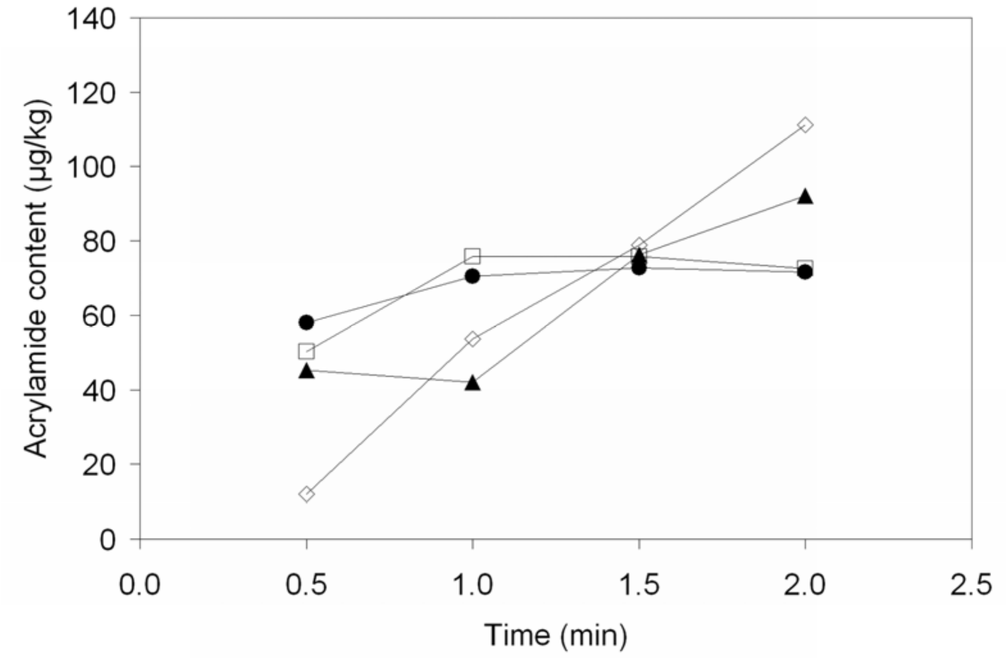

**Figure 3.17** Variation of acrylamide content in the coating part of chicken fingers having different flours in its batter formulation during microwave frying
(□) control, (◊) chickpea flour, (●) rice flour, (▲) soy flour

When the acrylamide contents of the samples having similar moisture contents (soy flour containing batter fried for 2.0 min and the other batter types fried for 1.5 min) were compared, similar acrylamide values were obtained for all types of batters (Figure 3.2, Figure 3.17 and Table A.31).

**Table 3.3** Amino acid profiles of different flour types

| Flour Type | Free amino acid content ( mg/ 100g ) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ala | Arg | Asn | Asp | Cys | Cys-Cys | Glu | Gln | Gly | His | Hpr | Leu-Ileu | Lys | Met | Phe | Pro | Ser | Thr | Tyr | Trp | Val |
| Soy | 69.6 | 23.7 | 22.6 | 10.4 | 15.1 | 67.2 | 4.4 | 15.1 | 8.7 | 8.9 | 3.1 | 7.5 | 44.6 | 4.2 | 6.9 | 18.7 | 8.1 | 9.6 | 50.9 | 10.3 | 9.8 |
| Chickpea | 13.2 | 70.2 | 42.1 | 10.3 | 24.4 | 46.4 | 2.7 | 4.9 | 4.2 | 7.8 | 2.1 | 2.2 | 27.8 | 2.2 | 2.7 | 7.1 | 5.5 | 6.3 | 6.9 | 51.1 | 3.3 |
| Rice | 9.6 | 0.2 | 0.2 | 1.3 | 0.6 | 2.2 | 0.3 | 1.4 | 0.6 | 0.2 | 0.3 | 0.2 | 0.5 | 0.0 | 0.2 | 1.2 | 0.5 | 0.4 | 0.6 | 0.1 | 0.8 |
| Wheat | 5.3 | 0.2 | 6.2 | 1.9 | 1.5 | 9.9 | 0.5 | 4.0 | 1.2 | 0.6 | 0.4 | 0.6 | 1.4 | 0.2 | 0.7 | 3.1 | 0.5 | 1.0 | 4.2 | 7.6 | 1.8 |
| Corn | 7.1 | 0.1 | 4.3 | 4.1 | 1.1 | 11.2 | 0.5 | 5.9 | 2.4 | 0.3 | 0.5 | 0.8 | 1.6 | 0.1 | 0.1 | 14.9 | 1.6 | 1.9 | 7.6 | 0.9 | 1.9 |

During microwave frying, as moisture content decreased acrylamide content increased continuously in batter formulations containing soy flour and chickpea flour (Figure 3.18). In the case of control and rice flour containing batter, acrylamide content remained constant below 25% moisture content. This may be due to the depletion of free amino acids in these formulations since they contain lower amounts of free amino acids and also protein (Table 3.1 and Table 3.3).

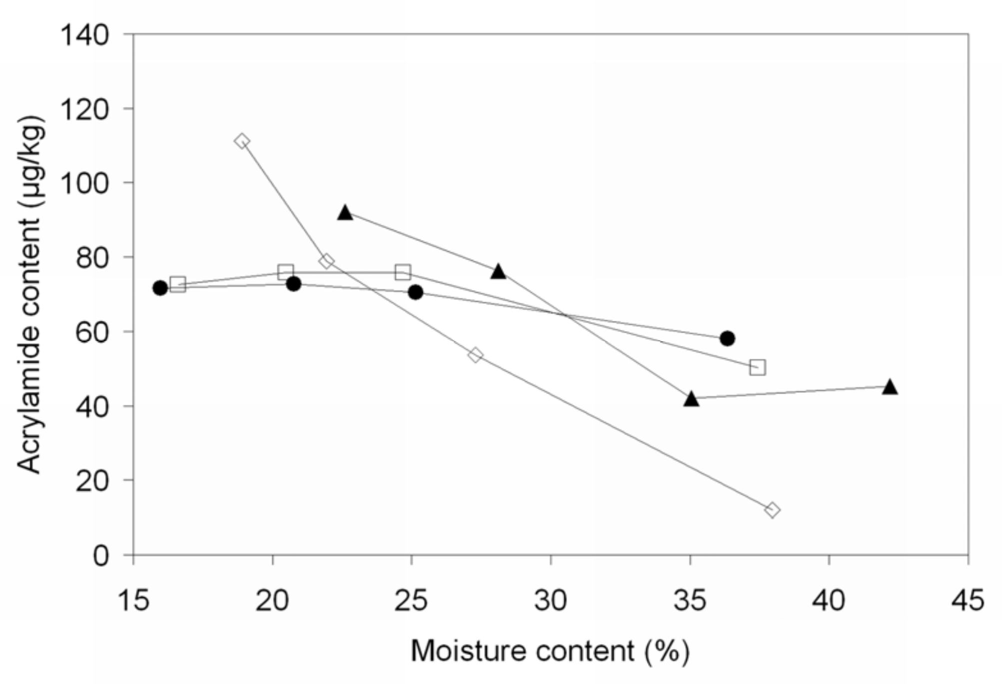

**Figure 3.18** Acrylamide content of coating part of microwave fried chicken fingers having different flours in its batter formulation for different times with respect to their corresponding moisture contents
(□) control, (◊) chickpea flour, (●) rice flour, (▲) soy flour

Although soy flour provided lighter colored samples with lower a* values compared to other flour types (Figure 3.8 and Figure 3.9), acrylamide content of batter containing this flour was not different from the other formulations (Figure 3.17). This shows that the color parameters may not always be a reliable indicator of acrylamide levels. Surdyk et al. (2004) showed that when the breads were baked at

270˚C for 15 min with higher levels of added fructose and asparagine, the color did not change significantly while the acrylamide content increased dramatically in crust.

The acrylamide contents of microwave fried samples for 1.5 min was compared with that of conventionally fried samples for 5.0 min (Figure 3.19). Microwave frying resulted in lighter colored samples (Figure 3.8 and Table 3.2) and lower acrylamide formation in the coatings prepared by different types of flours as compared to conventional frying (Figure 3.19 and Table A.32). Microwave frying resulted in 13.8% reduction in acrylamide content of control batter. Higher reduction rates were obtained with the other types of flours. The highest reduction rate (34.5%) was obtained in rice flour added batter. The reduction in acrylamide content in microwave frying can be explained by shorter frying time as compared to conventional frying. Sahin et al. (2007) obtained similar results for the microwave fried potato strips.

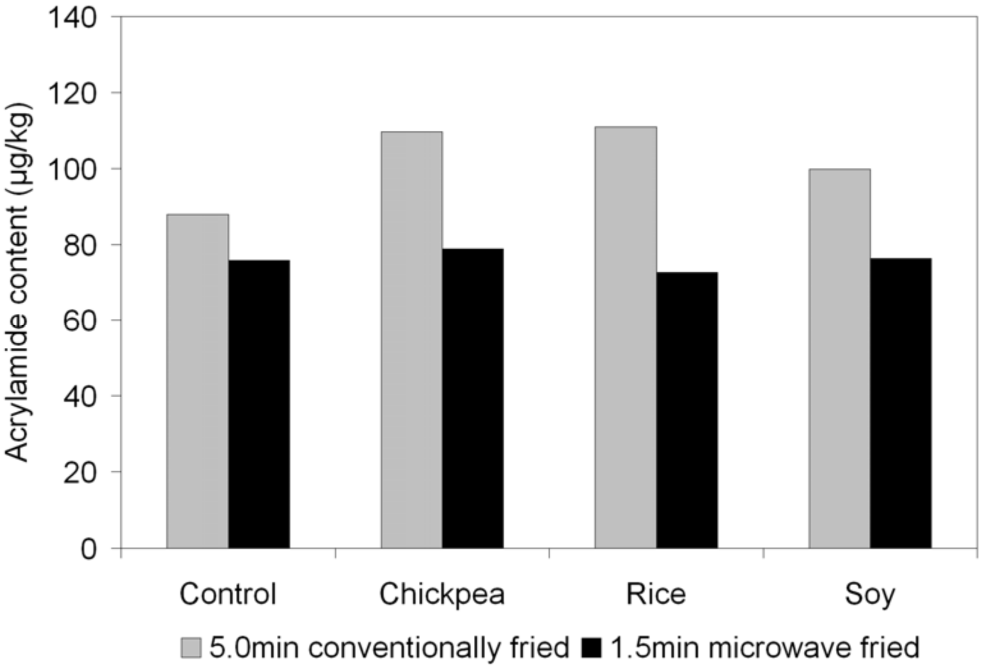

**Figure 3.19** Acrylamide content of coating part of chicken fingers having different flours

## 3.3 Effects of Flour Type and Frying Method on the Microstructure of Batter Coatings

SEM images of raw batters containing different types of flours can be seen in Figure 3.20. Dough is described as bicontinuous starch protein system (Hug-Iten et al., 1999). The swollen starch granules embedded in gluten protein matrix forming a continuous phase can be seen in the figure.

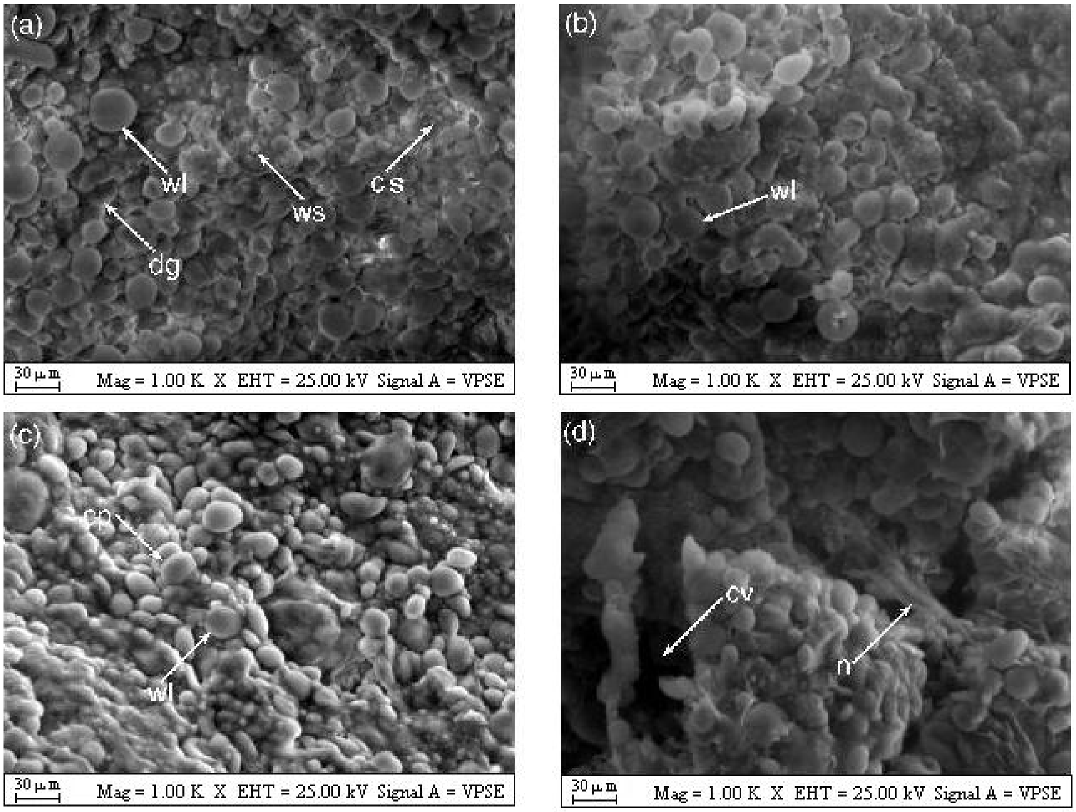

**Figure 3.20** SEM microstructure of dough with different flour types (a)control, (b)with addition of rice flour, (c)with addition of chickpea flour and (d) with addition of soy flour. Corn starch granule (cs), large (wl) and small (ws) wheat starch granules, chickpea starch granules (cp), degraded granule (dg), cavities (cv), protein network (n)

Control batter contains only wheat and corn flour in equal amounts. Wheat starch granules with two different sizes, larger lentil shaped granules and smaller round shaped granules can be observed in control batter (Figure 3.20 a) as reported by other researchers (Roman-Gutierrez et al., 2002; Llorca et al., 2001). The lentil shaped granules had a length of 12-30 μm and width of 16-29 μm and round shaped granules ranged in size from 4 to 9 μm. These results are consistent with literature (Lindeboom et al., 2004; Naruenartwongsakul et al., 2008). It is also possible to see corn starch granules in control batter which are known to be polygonal with a diameter of 3.5 μm (Llorca et al., 2001).

Rice starch granules are also small like corn starch granules. They are known to be polygonal in shape with a diameter of 2-10 μm (Lindeboom et al., 2004). Therefore, in SEM image of rice flour added batter (Figure 3.20 b), it was not easy to differentiate rice and corn starch granules. Small sized granules were embedded in protein matrix and their distribution was not homogeneous.

SEM image of chickpea added batter contained oval shaped granules (Figure 3.20 c). Singh et al. (2004) separated starch granules from different chickpea cultivars and showed the presence of large oval to small spherical shape granules with mean granule length and width of 17.0-20.1 μm and 11.0-14.4 μm, respectively.

Protein matrix was more distinct in soy flour containing batter (Figure 3.20 d). Starch granules seemed to be trapped in a protein network containing both wheat gluten and soy protein. Occurrence of some cavities was also observed. High protein content of soy flour may be the reason for this different structure (Table 3.1).

The images of outer surface of 1.5 min microwave fried batters were shown in Figure 3.21. Formation of many bubbles and vented holes with different sizes was observed on the outer surface of all types of fried batters. The reason might be the expansion of water vapor and entrapped air during frying. Some of the gas cells seemed to be collapsed. The gas cells were larger on the surface of control sample compared to others. Control batter contains more wheat flour (more gluten) so it may hold more gas inside (Figure 3.21a). Similar structures were reported in literature for wheat flour based fried batter coatings and fried dough (Naruenartwongsakul et al., 2008; Suarez et al., 2008). Chickpea flour showed similar appearance with control (Figure 3.21c). Similar to the observations in SEM images, specific volume and porosity values of microwave fried samples were found to be higher for control and chickpea flour containing batters as compared to others (Figure 3.12 and Figure 3.14).

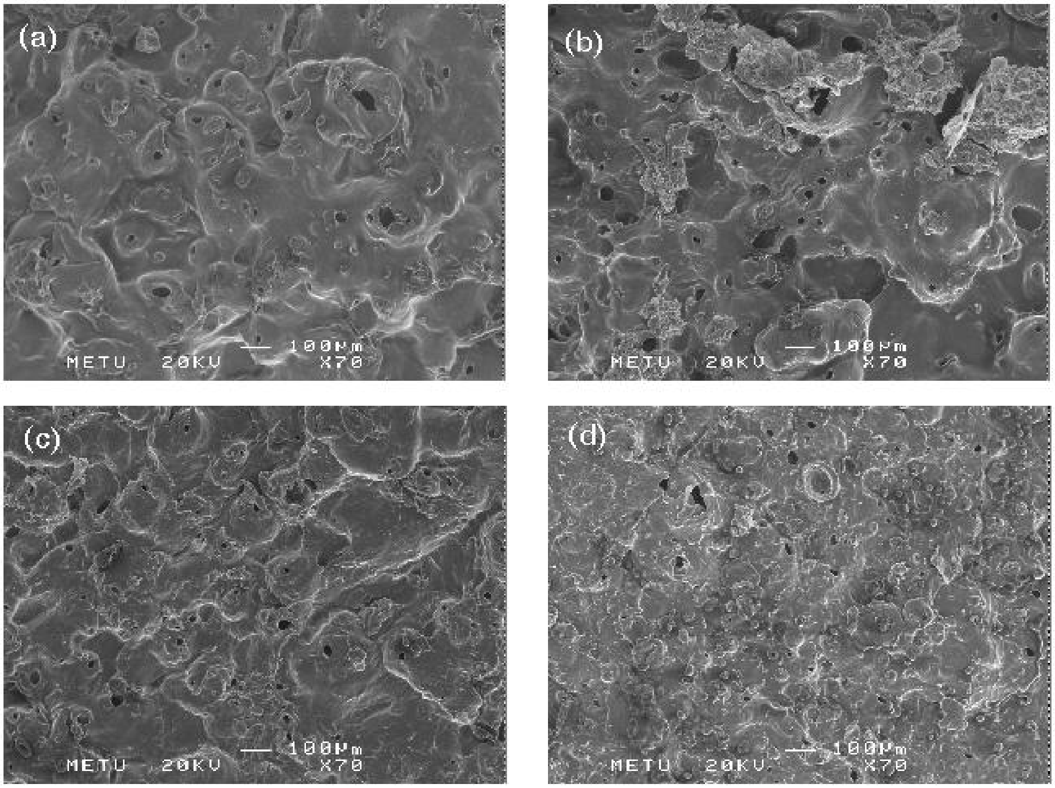

**Figure 3.21** SEM microstructure of outer surface of batter area for 1.5 min microwave fried chicken samples

(a)control, (b)with addition of rice flour, (c)with addition of chickpea flour and (d) and with addition of soy flour

In the case of rice flour containing batter, a continuous structure couldn't be observed (Figure 3.21b). There were some areas having different structure. Rice flour contains the lowest amount of protein compared to other flour types and also it has higher gelatinization enthalpy compared to wheat and corn flour which may affect the continuous film formation on the surface (Table 3.4). Higher gelatinization enthalpy in the case of rice flour means slower starch gelatinization as compared to other flours.

**Table 3.4** Thermal characteristics of different flour types

| Flour type | $T_0$ (°C) | $T_p$ (°C) | $T_c$ (°C) | (ΔH) J/g |
|---|---|---|---|---|
| Wheat | 58.55 | 63.05 | 71.01 | 4.192 |
| Corn | 67.16 | 73.33 | 78.80 | 5.034 |
| Rice | 61.71 | 68.81 | 78.96 | 5.368 |
| Chickpea | 67.16 | 73.06 | 82.46 | 5.548 |
| Soy | 75.25 | 80.59 | 88.02 | 0.4303 |

The outer surface of soy flour containing batter after frying was smoother (Figure 3.21d). That is, it has smaller sized gas cells on the surface. There were many vented holes but less gas cells. This may be due to the higher viscosity of batter containing soy flour. Soy flour is known to bind more water and to result in higher viscosity (Dogan et al., 2005b) which may be ascribed to its higher protein content (Table 3.1). It is known that if the viscosity of the batter is too high, it may prevent expansion of water vapor. Lower specific volume and porosity of samples prepared with soy flour containing batter are in consistent with this result (Figure 3.12 and Figure 3.14).

For the batter incorporated with soy flour, existence of some starch granules, both deformed and intact, were seen on the surface (Figure 3.21d). Water content may not be enough to fully gelatinize the starch granules in batter mixture because of the greater hydration capacity of soy flour. Aguilera et al. (2001) showed the importance of water for starch swelling. In their experiment, dry potato starch granules stayed almost intact in oil at 180°C. In another study, it was recorded that, the gelatinization of corn starch in a corn starch and soy protein concentrate composite was restricted by soy protein concentrate (Li et al., 2007).

The outer surfaces of samples fried for 1.5 min in microwave oven were more porous than conventionally fried ones for the same frying period (Figure 3.21 and Figure 3.22). This can be explained by the relatively large amounts of internal heating in microwave processing which results in increased moisture vapor generation inside a solid food material. This creates significant internal pressure and concentration gradients during microwave heating (Datta, 1990; Feng and Tang, 1998). In addition, conventional deep-fat frying provided less discontinuity of the film structure on the outer surface of rice flour containing batter.

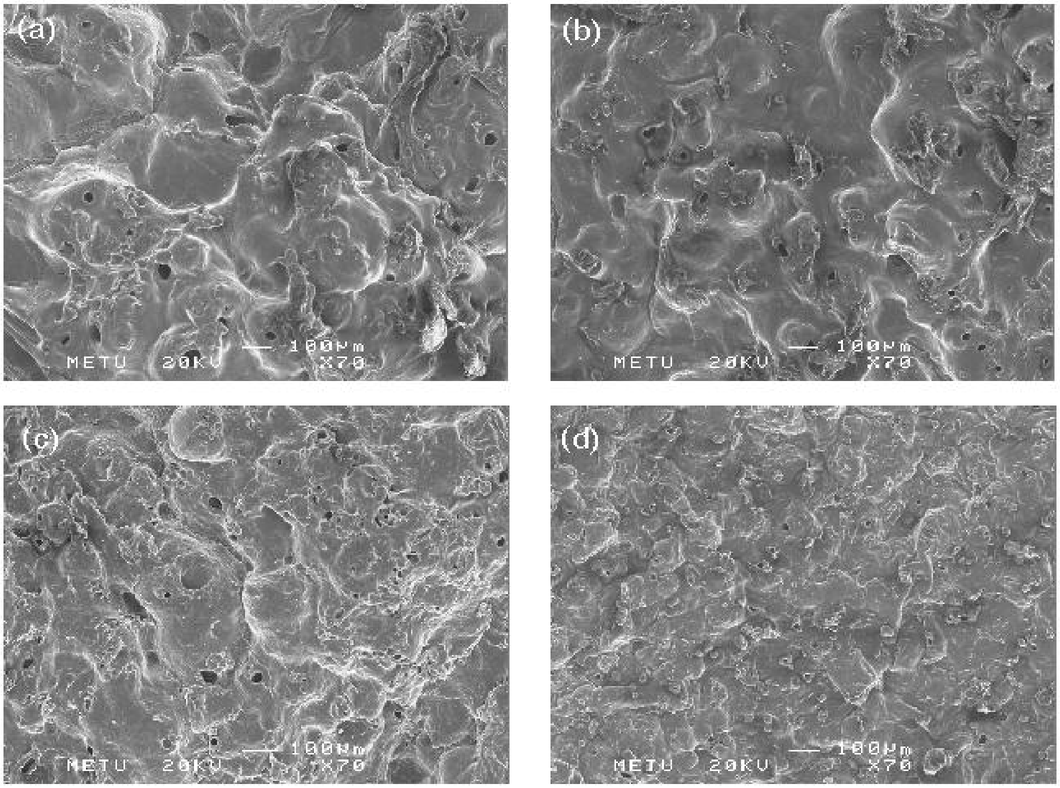

**Figure 3.22** SEM microstructure of outer surface of batter area for 1.5 min conventionally fried chicken sample
(a)control, (b)with addition of rice flour, (c)with addition of chickpea flour and (d) with addition of soy flour

In Figure 3.23, the images of outer surface of conventionally deep-fat fried batters for 5.0 min were shown. Surface of chickpea and soy flour containing batters were covered with air cells and vented holes but lower in number compared to control and rice flour containing batter. This may be related with the higher protein contents of chickpea and soy flours providing a veil like film over the surface during frying. Increasing frying time from 1.5 min to 5.0 min increased the number of gas cells and vented holes on the outer surface for control and rice flour containing sample while this change was not significant for chickpea and soy flour containing samples (Figure 3.22 and Figure 3.23).

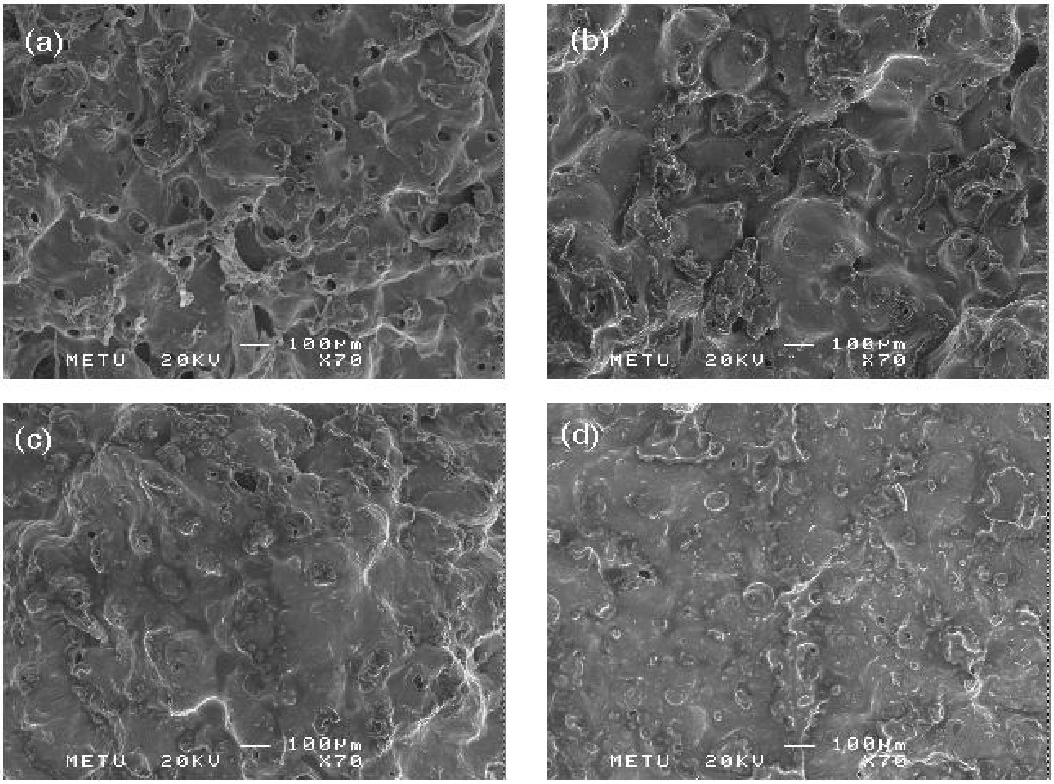

**Figure 3.23** SEM microstructure of outer surface area for 5.0 min conventionally fried chicken sample
(a)control, (b)with addition of rice flour, (c)with addition of chickpea flour and (d) with addition of soy flour

Since it is possible to fry products in a shorter time in microwave oven, it may not be correct to compare the products fried conventionally and using microwave for the same time. Therefore, the microstructure of microwave fried samples for 1.5 min was compared with that of conventionally fried samples for 5.0 min. Conventional deep-fat frying provided less number of vented holes on the outer surface of soy, chickpea and rice flour containing batters compared to microwave frying (Figure 3.21 and Figure 3.23). In addition, microwave frying caused formation of larger gas cells on control surface compared to 5.0 min conventional deep-fat frying. This may be due to the higher pressure gradient which leads to rapid removal of moisture in microwave frying.

The number of starch granules appeared on the surface of soy flour containing samples fried in microwave oven was higher as compared to those on the conventionally fried samples (Figure 3.21 and Figure 3.23). Incomplete starch gelatinization due to rapid removal of moisture during microwave frying might be the reason for the appearance of these starch granules.

In Figure 3.24 and Figure 3.25, the SEM images of the inner surfaces of different batters after 1.5 min microwave and 5.0 min conventional deep-fat frying can be observed, respectively. In microwave fried samples, the surface was covered with a film so underneath components can hardly be seen (Figure 3.24). There were vented holes on the surface instead of gas cells.

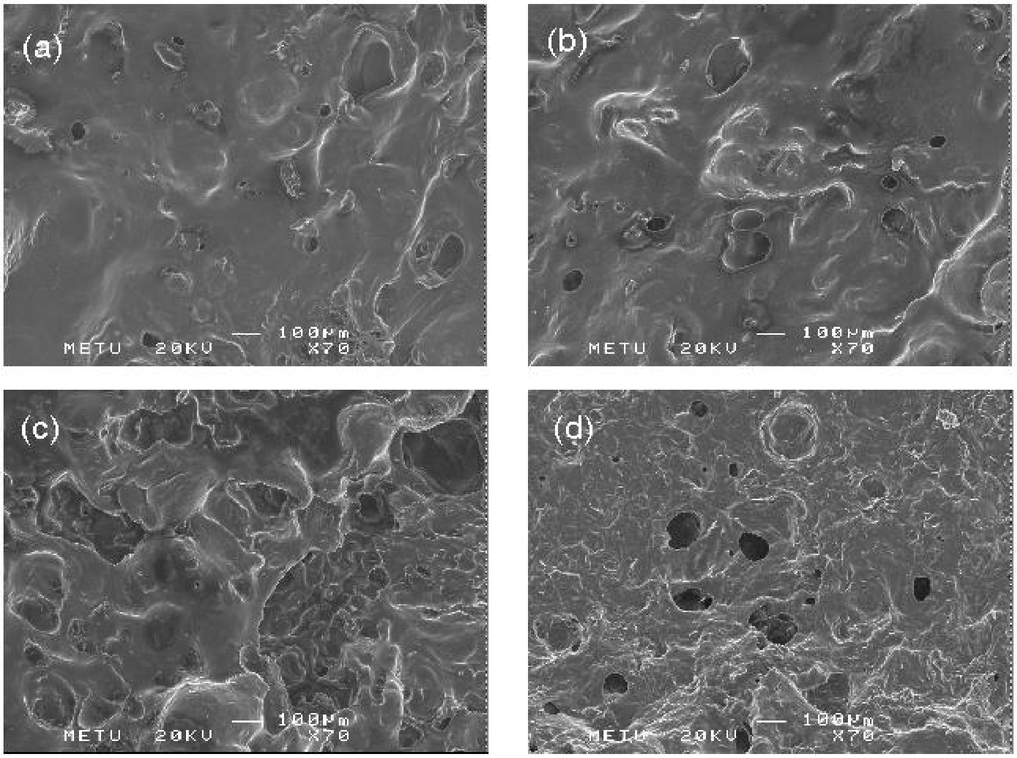

**Figure 3.24** SEM microstructure of inner surface of batter area for 1.5 min microwave fried chicken samples
(a)control, (b)with addition of rice flour, (c)with addition of chickpea flour and (d) with addition of soy flour

For all samples, the inner surface of batter was much more porous during conventional deep-fat frying compared to microwave frying (Figure 3.24 and Figure 3.25). Most probably, the batter and chicken portion were separated due to liquid pumping in microwave processing. Raw chicken tissue used in this study has nearly 75% moisture content. During microwave heating of a high moisture food, pressure rises much faster and reaches a much higher value than that occurs during conventional heating (Datta, 1990). This may result the water to be pumped across the chicken and batter coating interface without a phase change through these vented holes. Therefore, inner and outer surfaces of microwave fried samples were quite different (Figure 3.21 and Figure 3.24). Moisture contents of chicken parts of samples fried using microwave for 1.5 min were lower than samples fried conventionally for 5 min (Figure 3.4 and Figure 3.5)

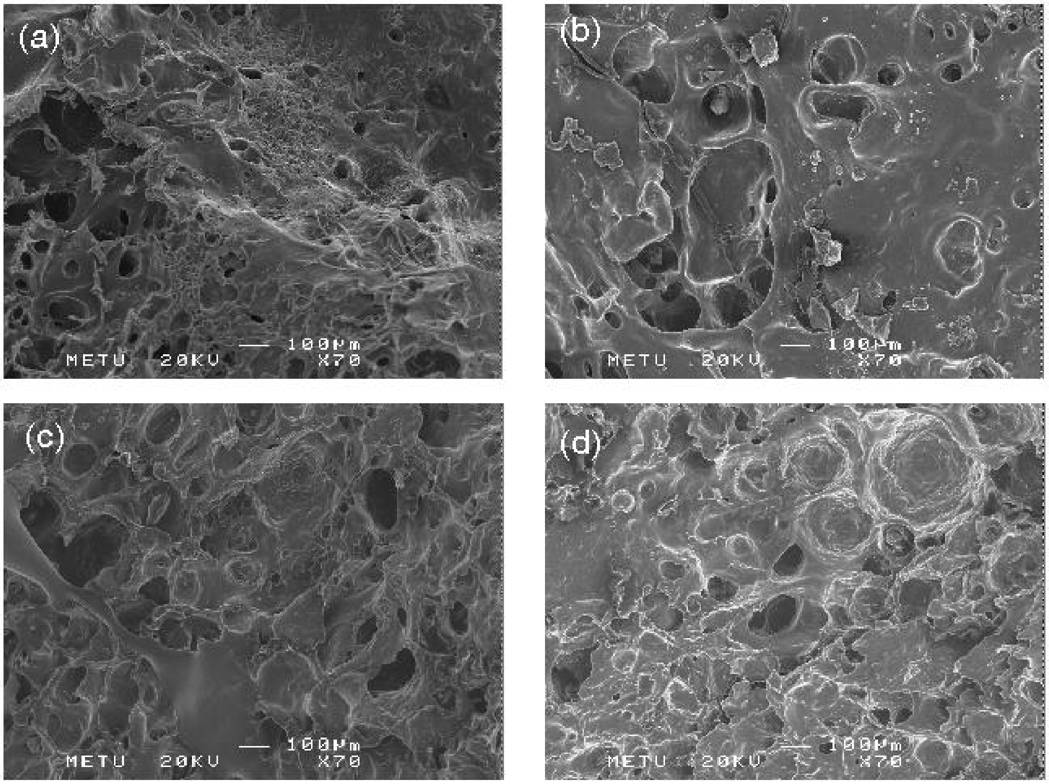

**Figure 3.25** SEM microstructure of inner surface of batter area for 5 min conventionally deep-fat fried chicken sample
(a)control, (b)with addition of rice flour, (c)with addition of chickpea flour and (d) with addition of soy flour

## 3.4 Magnetic Resonance Images of the Temperature Distribution in Chicken Fingers

Magnetic resonance images of the temperature distribution in chicken fingers are shown in Figure 3.26. The images from different slices of chicken fingers fried for 2 minutes in a deep-fat fryer are displayed. Temperature distribution is almost homogeneous at the center of the slices whereas the temperature distributions at the edges and the periphery are not homogeneous. A couple of points in slice 1 and slice 2 and some areas at the upper part of the slice 3 have the same color with the background. This means that there is no signal coming from these areas which may be explained by the formation of some cracks in the chicken sample during frying.

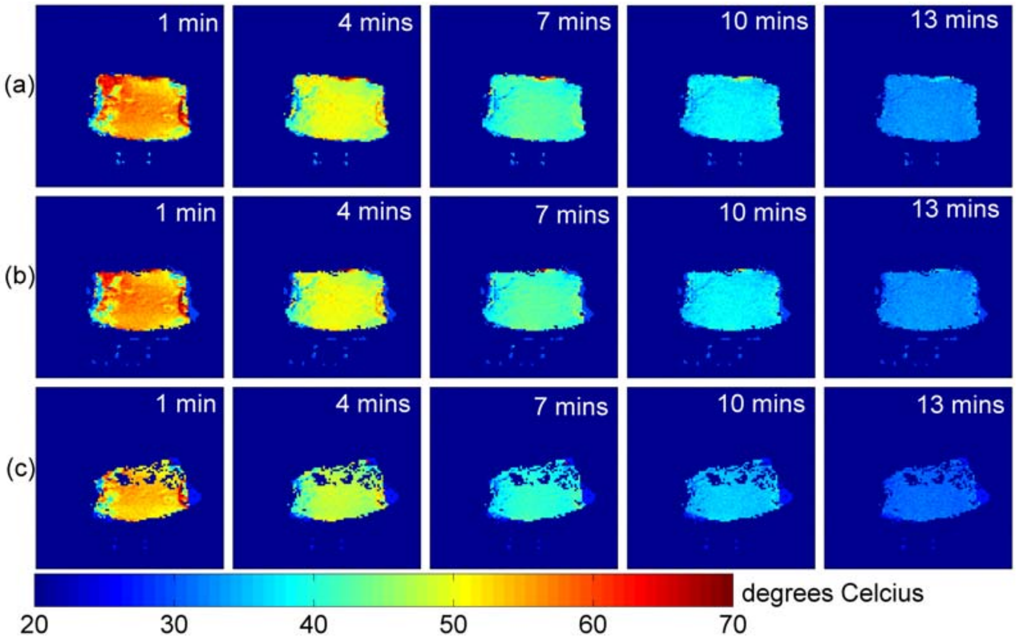

**Figure 3.26** Comparison of temperature maps in slice 1 (a), slice 2 (b) and slice 3 (c) of a chicken finger fried in deep fat fryer for 2 min during cooling

The shapes of different slices became more irregular when the frying time is increased to 5 minutes (Figure 3.27). When muscle is heated, protein denaturation and coagulation occur which leads to shrinkage and loss of moisture. Kassama and Ngadi (2003) have shown that the volumetric shrinkage of deep fat fried chicken breast samples increased significantly with increasing frying time and was temperature dependent. Moreover, shrinkage in meat products is known to be anisotropic. Meat can shrink in two dimensions, while expanding in the third dimension (Offer et al., 1984; Rowe, 1974) which may be a reason for this irregularity. Increasing the frying time also leads to more crack formation and significantly higher mean temperature with higher standard deviation within sample (Table 3.5, Table A.33 and Table A.34). This means that more nonuniform temperature distribution was obtained throughout the sample.

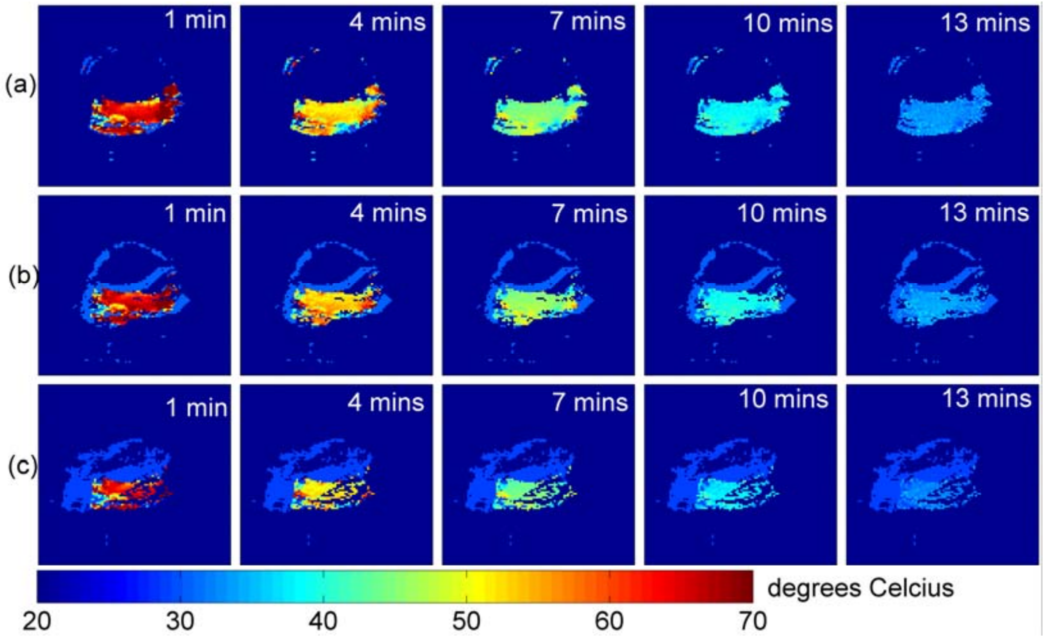

**Figure 3.27** Comparison of temperature maps in slice 1 (a), slice 2 (b) and slice 3 (c) of a chicken finger fried in deep fat fryer for 5 min during cooling

**Table 3.5** Mean and standard deviation of histograms obtained from the temperature maps of samples at 1 min and 13 min of holding time. The average values of three replications were taken

| Slice Number | Holding Time(min) | Microwave fried 0.5min | | Microwave fried 1.5 min | | Deep fat fried 2 min | | Deep fat fried 5min | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD* | Mean | SD | Mean | SD | Mean | SD |
| Slice 1 | 1 min | 60.03 | 5.19 | 61.51 | 11.52 | 58.11 | 6.61 | 64.14 | 8.99 |
| | 13 min | 33.19 | 0.84 | 31.79 | 2.41 | 33.05 | 1.13 | 33.57 | 1.80 |
| Slice 2 | 1 min | 62.56 | 5.38 | 64.12 | 10.83 | 58.08 | 6.50 | 64.57 | 9.05 |
| | 13 min | 35.31 | 0.86 | 33.50 | 2.41 | 32.93 | 1.04 | 34.36 | 1.48 |
| Slice 3 | 1 min | 59.06 | 5.17 | 62.37 | 10.26 | 55.51 | 6.05 | 63.15 | 8.14 |
| | 13 min | 31.01 | 0.87 | 30.59 | 2.34 | 30.59 | 1.01 | 32.61 | 1.65 |

* SD: standard deviation

Photographs of 3 axial slices at the same positions as the MR images obtained in samples fried for 2 min and 5 min in a deep fat fryer are shown in Figure 3.28. Increasing the frying time resulted in larger crack formation in addition to the smaller ones. The position and the size of these cracks vary through the sample. An empty space between the coating and the chicken tissue is easily distinguished from a crack within the sample tissue (Figure 3.28). In the MR image data, however, it is difficult to discriminate between the crack within chicken tissue and a void at the coating surrounding the chicken tissue (Figure 3.27).

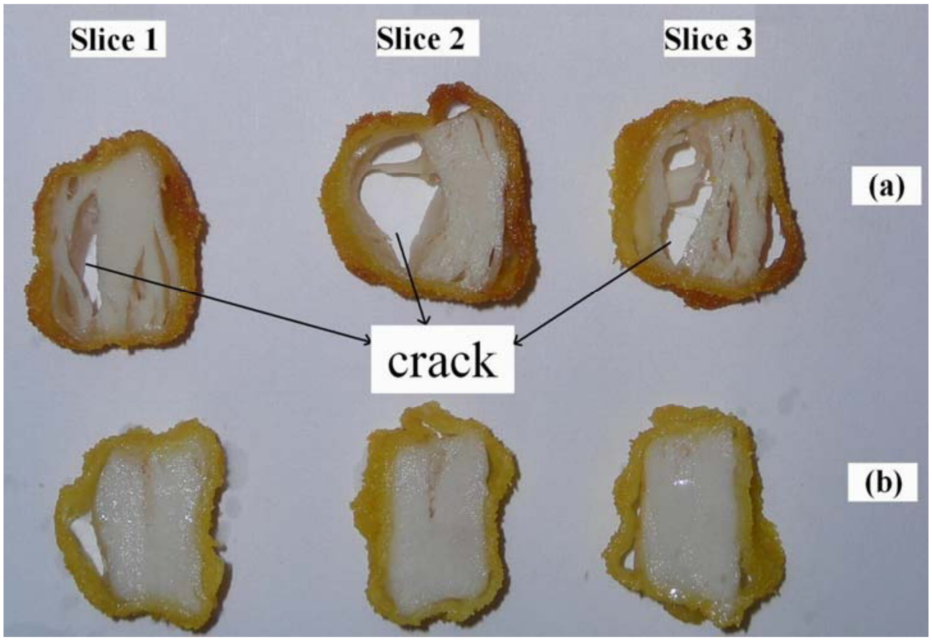

**Figure 3.28** Photographs of 3 different slices in a chicken finger fried in deep fat fryer for 5 min (a) and 2 min (b)

The samples have already cooled down between the time interval when they were taken out of the fryer and put in the magnet bore. Since heat transfer occurs during this time through convection with air, periphery of the slices and the surfaces surrounding the crack areas cool down more rapidly. This rapid cooling may be one of the reasons for the presence of light blue colored areas corresponding to approximately 30°C in the temperature maps.

The oil absorbed by the sample during frying may also contribute to the MR signal. However, it is known that temperature related changes of the local magnetic field in fat tissue are completely different than that of water. De Poorter (1995) showed that temperature dependence of PRF changes is induced almost completely by susceptibility effects in fat tissue while it is small for muscle tissue. Therefore, the temperature of oil may not be reflected in MR images and the chicken tissue absorbing oil accordingly may be seen as if it has low temperature value. In temperature maps, more light colored areas are observed at higher frying time. This may be related with the increased oil uptake with increasing frying time (Gamble et al., 1987; Saguy and Pinthus, 1995).

The histogram plots of the temperature maps are obtained by distributing the pixels into equally spaced bins with a width of 1°C (Figure 3.29). The internal thermal equilibration during overall cooling time of samples can be more clearly observed in the histogram plots where the spread of the temperature values decreases accompanied by a shift to left.

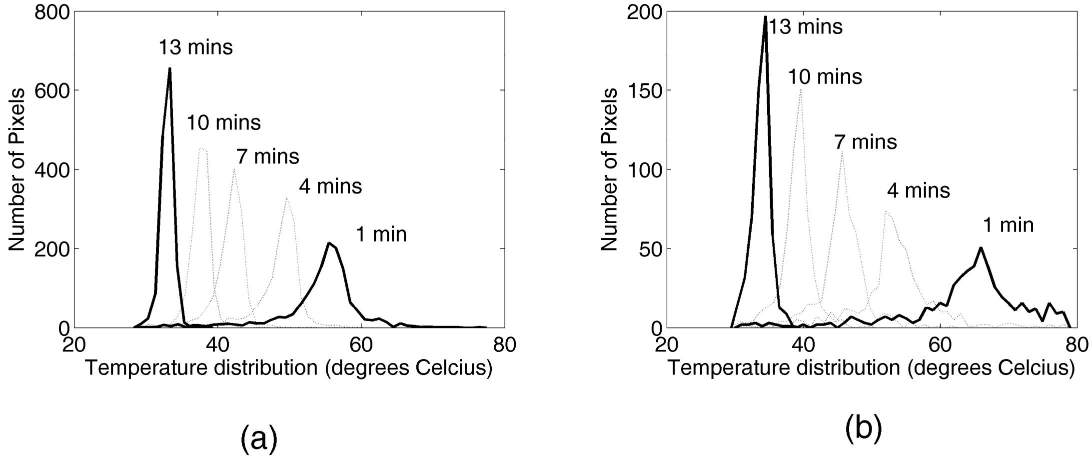

**Figure 3.29** Temperature histograms from 5 MR images taken during 13 min of cooling period in middle slice of the samples fried for 2 min (a) and 5 min (b) in deep fat fryer

Center temperatures of chicken finger samples were measured during microwave frying and deep fat frying as well by fiber optic probes for 2 min and 5 min, respectively (Figure 3.30). Center temperature of chicken finger rapidly increased to boiling point of water and then stayed between 98-106°C during 2 min microwave frying time. However, it took longer time, 145 sec, for the center temperature of chicken finger fried in conventional deep fat fryer to reach 98°C. Then, the temperature stayed nearly constant around 97-98°C. This is an expected result since microwave heating creates an internal heat generation within the sample. The cycling of temperature during microwave frying is due to the on-off cycling of microwaves depending on the microwave power.

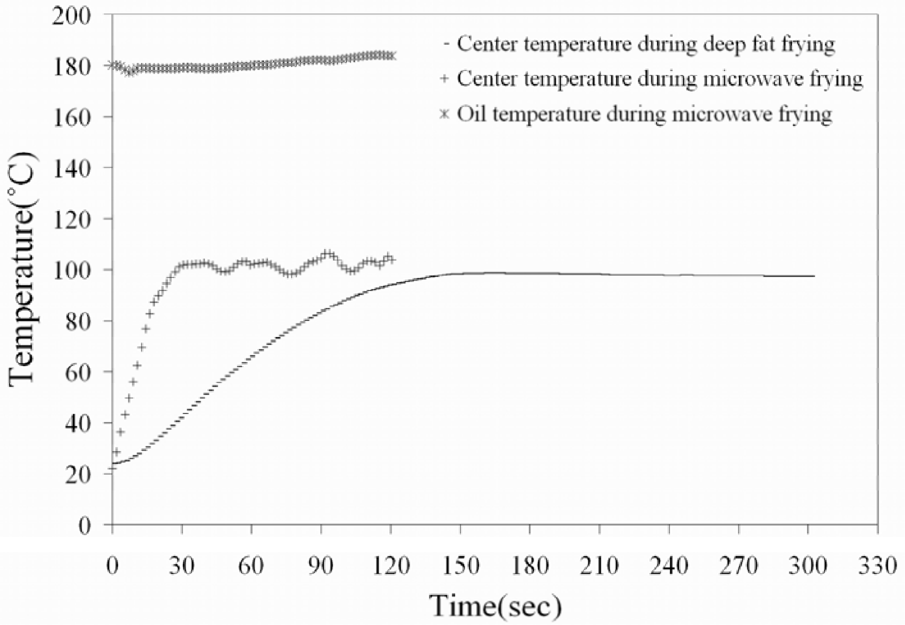

**Figure 3.30** Center temperature of chicken fingers fried in deep fat fryer and in microwave oven

The effect of microwave heating on the center temperature of the product at lower times of frying can also be seen from the temperature maps. Temperature map at 1 min are redder (higher temperature values) for the sample fried in microwave oven for 0.5 min (Figure 3.31) as compared to that fried in deep fat fryer for 2 min (Figure 3.26). Enhanced heating was observed especially at the bottom edge as well as around the center. Although the average temperature of 0.5 min microwave fried sample was found to be slightly higher (Table 3.5), this difference was not statistically significant (Table A.35).

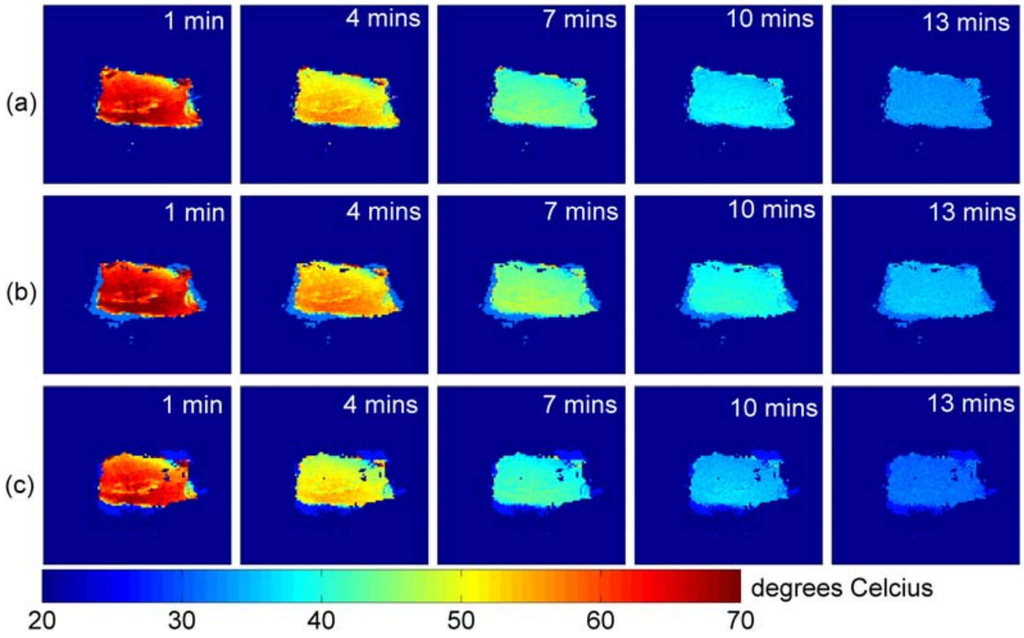

**Figure 3.31** Comparison of temperature maps in slice 1 (a), slice 2 (b) and slice 3 (c) of a chicken finger fried in microwave oven for 0.5 min during cooling

An increase in microwave frying time from 0.5 min to 1.5 min created a significant change in the structure of fried chicken muscle (Figure 3.31 and Figure 3.32). Formation of many cracks is observed in all slices. It is known that oil penetrates the crust through the pores created by the evaporation. Increased amount of low temperature areas within 1.5 min microwave fried sample immediately after frying may be an indicator of higher oil absorption resulting from higher crack formation.

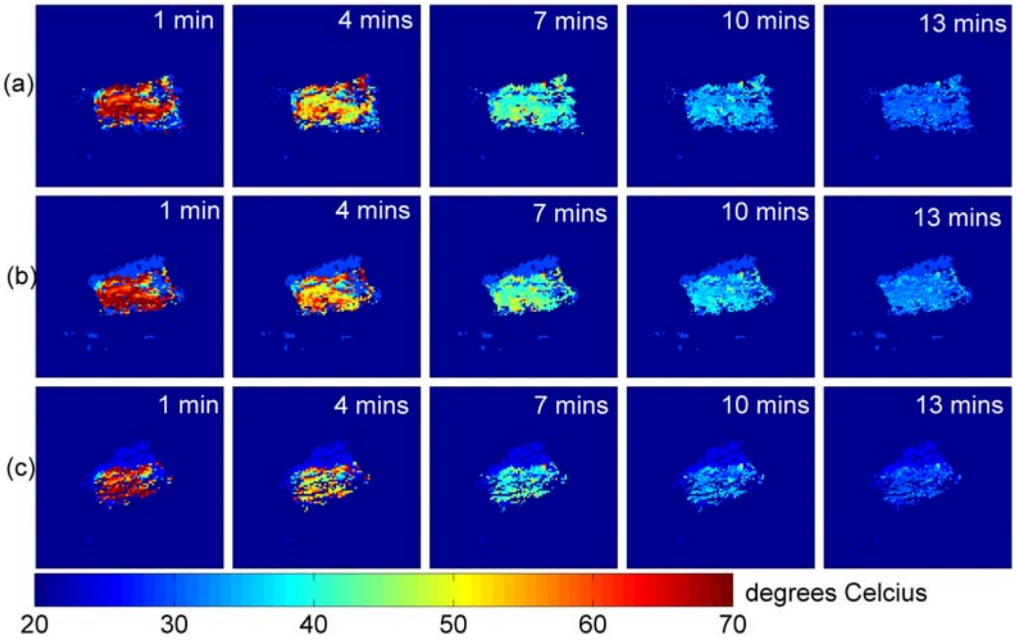

**Figure 3.32** Comparison of temperature maps in slice 1 (a), slice 2 (b) and slice 3 (c) of a chicken finger fried in microwave oven for 1.5 min during cooling

Temperature distribution became more heterogeneous at higher microwave frying time which can be seen by the broader spread of temperature values in histograms (Figure 3.33). During microwave frying, moisture migrates to the surface of the sample due to concentration gradient created by surface drying and also due to high internal pressure. The heterogeneous distribution of the remaining moisture within the chicken sample may result in localized heating. Nonuniform thickness of the coating material around the chicken sample and change in orientation of the chicken sample in hot oil during frying will influence the penetration depth and power delivered into the product (James, 1993; George and Burnett, 1991), respectively. These may also result in uneven heating.

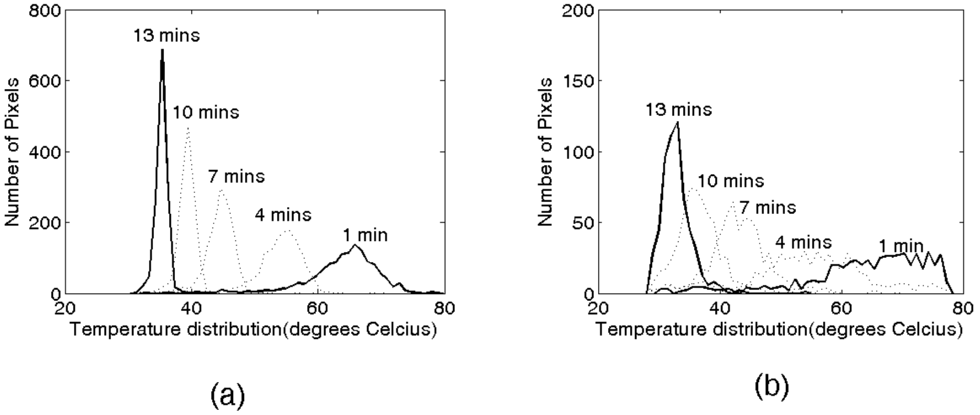

**Figure 3.33** Temperature histograms from 5 MR images taken during 13 min of cooling period in middle slice of the samples fried for 0.5 min (a) and 1.5 min (b) in microwave oven

Crack formation can be monitored by counting void formation in the MR images. The voxels in the crack areas have “0” intensity value. The percentage of voxels with ‘0’ value was calculated in a region of interest that covers whole slice. Three replications were done for each sample and the average values are shown in Figure 3.34. Although the time is reduced, 1.5 min microwave frying resulted in more crack formation compared to 5 min conventional deep-fat frying. It is known that relatively large amounts of internal heating results in increased moisture vapor generation inside a solid food material, which creates significant internal pressure and concentration gradients during microwave heating (Datta, 1990; Feng and Tang, 1998). The moisture content of chicken tissue decreased to 61.96 % by frying for 5 min in deep fat fryer whereas it had 55.40% moisture content at the end of 1.5 min microwave frying (Figure 3.4 and Figure 3.5). This higher rate of moisture loss may create additional stress within the chicken tissue which increased crack formation.

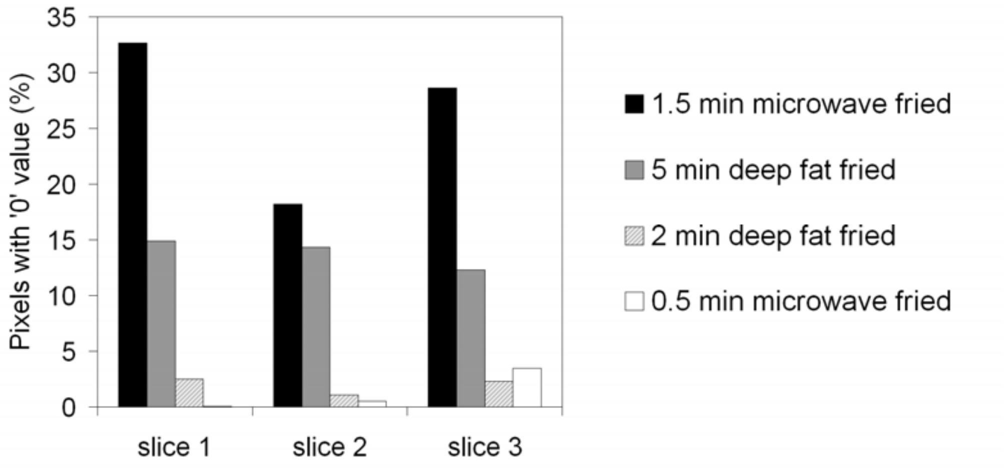

**Figure 3.34** Percent of pixels with '0' value within 3 different slices of chicken fingers fried in deep fat fryer and microwave oven

All samples have nearly uniform temperature distribution after 13 minutes of cooling which is seen as a narrow peak in histograms (Figure 3.35). The lower voxel number at higher frying times is due to less signal obtained from these samples as a result of moisture loss. The lower magnitude of MR signal resulting from the loss of moisture at higher frying times did not affect the accuracy of temperature measurements.

In both frying methods, increased frying time resulted in higher mean temperature (Table A.33 and Table A.36) and higher standard deviation (Table A.34 and Table A.37) of the temperature maps and more crack formation (Figure 3.34) in samples. This shows broader distribution of temperature values with increasing frying time. Samples fried using microwave for 1.5 min had the highest standard deviation in all slices which means that it resulted in a more heterogeneous temperature distribution in the sample (Table 3.5 and Table A.38). There was no significant difference between the slices when standard deviation values were considered (Table A.34 and Table A.37).

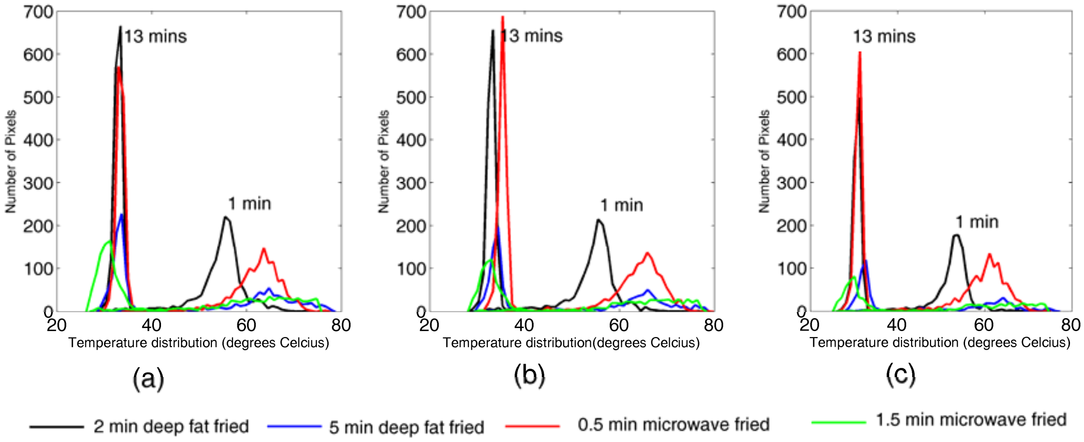

**Figure 3.35** Temperature histograms from 2 MR images taken at 1min and 13 min of cooling in slice 1 (a) slice 2 (b) and slice 3 (c) of the sample

# CONCLUSIONS

Using microwaves as a frying method decreased frying time significantly, but increased moisture loss as compared to conventional frying. Lighter colored samples and similar oil contents were obtained with microwave frying as compared to conventional frying. Microwave frying time was found to be effective on quality parameters except oil content. Microwave fried samples was found to be more porous and have lower hardness values than the conventionally fried ones. Microwave frying resulted in lower acrylamide formation as compared to conventional frying.

Samples fried for 1.5 min in microwave oven and 5 min in conventional deep-fat frying were acceptable for consumption. Usage of all flour types except soy flour resulted in approximately the same moisture content in the coating part and provided similar color development after 1.5 min of microwave frying. Soy flour provided the highest coating pick-up and retained more moisture in coating and chicken parts of the fingers during both frying methods. Lighter colored samples with lower oil content in the coating part were obtained with soy flour during microwave frying. For conventionally fried samples also, soy flour added coating had lower oil content compared to chickpea and rice flour added ones. Control samples provided the highest hardness values during microwave frying and also conventional frying. More porous samples with decreased hardness values were obtained with chickpea flour addition to the batter formulation in 1.5 min microwave fried samples as compared to soy and rice flour. Acrylamide contents were found to be similar for all types of flours in coating part of chicken fingers. As a conclusion, soy flour containing batter can be recommended to be used in both microwave and conventional deep-fat frying.

Microstructure of fried batter was different for different batter formulations. Soy flour containing batter resulted in smallest size gas cells for both frying methods. SEM results were found to be correlated with specific bulk volume and porosity measurements. Appearance of inner and outer surfaces of batter samples fried in microwave oven and conventional deep-fat fryer was quite different. In general, there were many gas cells and vented holes on the outer surface while only vented holes on the inner surface of microwave fried samples. In microwave frying smoother inner surface for all samples were observed as compared to conventional frying.

Internal temperature distribution varied proportionally with increasing frying time in both microwave and conventional frying. Internal thermal equilibrium is reached in all samples after 13 minutes of holding time. Increased frying time resulted in structural heterogeneity due to increased rate of crack formation. The sample fried in microwave oven for 1.5 min had a more nonuniform temperature distribution.

## RECOMMENDATIONS

Further research may be done to determine the effects of different ingredients in batter formulation like combinations of starch and proteins, and their concentrations on quality parameters of microwave fried products. The effect of microwave frying on chicken myofibrillar proteins can be studied. It is important to assess frying oil quality because a certain amount of oil is absorbed by food during frying. The physical and chemical changes of frying oil during microwave frying may be investigated. In addition, the moisture and/or oil distribution in microwave fried products may be visualized by using magnetic resonance imaging.

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# APPENDIX A

# ANOVA AND TUKEY TABLES

**Table A.1** ANOVA and Tukey Multiple Comparison Test Tables for coating pick-up of samples with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 1076.560 | 1076.560 | 358.850 | 2719.99 | 0.000 |
| Error | 24 | 3.170 | 3.170 | 0.130 | | |
| Total | 27 | 1079.730 | | | | |

Tukey Simultaneous Tests
Response Variable Coating
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -0.0929 | 0.1942 | -0.4783 | 0.9632 |
| Rice | 1.3000 | 0.1942 | 6.6958 | 0.0000 |
| Soy | 14.6657 | 0.1942 | 75.5374 | 0.0000 |
| Flour Type = Control subtracted from: | | | | |
| Rice | 1.3930 | 0.1942 | 7.1740 | 0.0000 |
| Soy | 14.7590 | 0.1942 | 76.0160 | 0.0000 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | 13.3700 | 0.1942 | 68.8400 | 0.0000 |

**Table A.2** ANOVA and Tukey Multiple Comparison Test Tables for moisture content of coating part of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 666.230 | 485.800 | 161.930 | 50.58 | 0.000 |
| Frying Time | 3 | 2615.960 | 2615.960 | 871.990 | 272.36 | 0.000 |
| Error | 41 | 131.270 | 131.270 | 3.200 | | |
| Total | 47 | 3413.460 | | | | |

Tukey Simultaneous Tests
Response Variable M. Content of Coating %
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|---|
| Control | -1.6510 | | 0.7789 | -2.1190 | 0.1640 |
| Rice | -1.9060 | | 0.7905 | -2.4120 | 0.0907 |
| Soy | 5.5620 | | 0.7656 | 7.2650 | 0.0000 |
| Flour Type = Control subtracted from: | | | | | |
| Rice | -0.2556 | | 0.7171 | -0.3565 | 0.9843 |
| Soy | 7.2128 | | 0.6921 | 10.4221 | 0.0000 |
| Flour Type = Rice subtracted from: | | | | | |
| Soy | 7.4680 | 0.7049 | 0.7049 | 10.6000 | 0.0000 |

**Table A.3** ANOVA and Tukey Multiple Comparison Test Tables for moisture content of coating part of 1.5 min microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 115.333 | 115.333 | 38.444 | 14.26 | 0.001 |
| Error | 8 | 21.562 | 21.562 | 2.695 | | |
| Total | 11 | 136.895 | | | | |

Tukey Simultaneous Tests
Response Variable M. Content of Coating %
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -1.4600 | 1.3400 | -1.0890 | 0.7054 |
| Rice | -1.1630 | 1.3400 | -0.8680 | 0.8211 |
| Soy | 6.1730 | 1.3400 | 4.6050 | 0.0076 |

Flour Type = Control subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Rice | 0.2967 | 1.3400 | 0.2213 | 0.9959 |
| Soy | 7.6333 | 1.3400 | 5.6945 | 0.0020 |

Flour Type = Rice subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Soy | 7.3370 | 1.3400 | 5.4730 | 0.0026 |

**Table A.4** ANOVA and Tukey Multiple Comparison Test Tables for moisture content of coating part of 5 min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 64.609 | 64.609 | 21.536 | 13.47 | 0.000 |
| Error | 13 | 20.780 | 20.780 | 1.598 | | |
| Total | 16 | 85.389 | | | | |

Tukey Simultaneous Tests
Response Variable M. Content of Coating %
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -1.6000 | 0.8724 | -1.8340 | 0.3020 |
| Rice | -2.6140 | 0.7403 | -3.5310 | 0.0170 |
| Soy | 3.8050 | 1.0137 | 3.7540 | 0.0113 |
| Flour Type = Control subtracted from: | | | | |
| Rice | -1.0140 | 0.9233 | -1.0980 | 0.6968 |
| Soy | 5.4050 | 1.1541 | 4.6830 | 0.0021 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | 6.4190 | 1.0580 | 6.0680 | 0.0002 |

**Table A.5** ANOVA and Tukey Multiple Comparison Test Tables for moisture content of chicken part of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 217.800 | 226.880 | 75.630 | 21.73 | 0.000 |
| Frying Time | 3 | 1369.550 | 1369.550 | 456.520 | 131.18 | 0.000 |
| Error | 40 | 139.210 | 139.210 | 3.480 | | |
| Total | 46 | 1726.560 | | | | |

Tukey Simultaneous Tests
Response Variable M. Content of Chicken %
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -3.0310 | 0.7800 | -3.8860 | 0.0020 |
| Rice | -1.8480 | 0.7616 | -2.4260 | 0.0884 |
| Soy | 2.8180 | 0.7616 | 3.7010 | 0.0035 |

Flour Type = Control subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Rice | 1.1830 | 0.7800 | 1.5170 | 0.4369 |
| Soy | 5.8490 | 0.7800 | 7.5000 | 0.0000 |

Flour Type = Rice subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Soy | 4.6660 | 0.7616 | 6.1260 | 0.0000 |

**Table A.6** ANOVA and Tukey Multiple Comparison Test Tables for moisture content of chicken part of 5min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 55.843 | 55.843 | 18.614 | 29.16 | 0.000 |
| Error | 13 | 8.298 | 8.298 | 0.638 | | |
| Total | 16 | 64.141 | | | | |

Tukey Simultaneous Tests
Response Variable M. Content of Chicken %
All Pairwise Comparisons among Levels of Flour Types

| Flour Type = Chickpea subtracted from | | | | |
|---|---|---|---|---|
| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
| Control | -1.9000 | 0.5008 | -3.7940 | 0.0105 |
| Rice | -2.3500 | 0.5008 | -4.6920 | 0.0021 |
| Soy | 3.5430 | 0.6406 | 5.5310 | 0.0005 |
| Flour Type = Control subtracted from: | | | | |
| Rice | -0.4500 | 0.5649 | -0.7966 | 0.8548 |
| Soy | 5.4425 | 0.6919 | 7.8661 | 0.0000 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | 5.8930 | 0.6919 | 8.5170 | 0.0000 |

**Table A.7** ANOVA and Tukey Multiple Comparison Test Tables for moisture content of chicken part of 1.5 min microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 73.417 | 73.417 | 24.472 | 8.19 | 0.011 |
| Error | 7 | 20.926 | 20.926 | 2.989 | | |
| Total | 10 | 94.343 | | | | |

Tukey Simultaneous Tests

Response Variable M. Content of Chicken %

All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -4.7430 | 1.5780 | -3.0050 | 0.0744 |
| Rice | -1.6570 | 1.4120 | -1.1740 | 0.6604 |
| Soy | 2.8000 | 1.4120 | 1.9830 | 0.2789 |
| **Flour Type = Control subtracted from:** | | | | |
| Rice | 3.0870 | 1.5780 | 1.9560 | 0.2885 |
| Soy | 7.5430 | 1.5780 | 4.7790 | 0.0084 |
| **Flour Type = Rice subtracted from:** | | | | |
| Soy | 4.4570 | 1.4120 | 3.1570 | 0.0610 |

**Table A.8** ANOVA Table for moisture content of coating part of 1.5 min microwave fried and 5 min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Frying Method | 2 | Conventional, Microwave |
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 2.977 | 2.977 | 2.977 | 4.68 | 0.119 |
| Flour Type | 3 | 60.440 | 60.440 | 20.147 | 31.66 | 0.009 |
| Error | 3 | 1.909 | 1.909 | 0.636 | | |
| Total | 7 | 65.326 | | | | |

**Table A.9** ANOVA Table for moisture content of chicken part of 1.5 min microwave fried and 5 min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Frying Method | 2 | Conventional, Microwave |
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 90.512 | 115.433 | 115.433 | 67.10 | 0.000 |
| Flour Type | 3 | 118.917 | 118.917 | 39.639 | 23.04 | 0.000 |
| Error | 23 | 39.566 | 39.566 | 1.720 | | |
| Total | 27 | 248.996 | | | | |

**Table A.10** ANOVA and Tukey Multiple Comparison Test Tables for oil content of coating part of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 668.560 | 658.850 | 219.620 | 87.78 | 0.000 |
| Frying Time | 3 | 3.840 | 3.840 | 1.280 | 0.51 | 0.677 |
| Error | 27 | 67.550 | 67.550 | 2.500 | | |
| Total | 33 | 739.950 | | | | |

Tukey Simultaneous Tests

Response Variable O. Content of Chicken %

All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -0.4730 | 0.7703 | -0.6100 | 0.9268 |
| Rice | 0.9000 | 0.7909 | 1.1400 | 0.6698 |
| Soy | -9.8420 | 0.7703 | -12.780 | 0.0000 |

Flour Type = Control subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Rice | 1.3730 | 0.7703 | 1.7800 | 0.3035 |
| Soy | -9.3690 | 0.7503 | -12.490 | 0.0000 |

Flour Type = Rice subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Soy | -10.740 | 0.7703 | -13.940 | 0.0000 |

**Table A.11** ANOVA and Tukey Multiple Comparison Test Tables for oil content of coating part of 1.5 min microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 87.041 | 87.041 | 29.014 | 67.03 | 0.000 |
| Error | 5 | 2.164 | 2.164 | 0.433 | | |
| Total | 8 | 89.205 | | | | |

Tukey Simultaneous Tests
Response Variable O. Content of Coating %
All Pairwise Comparisons among Levels of Flour Types

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Flour Type = Chickpea subtracted from | | | | |
| Control | -2.8570 | 0.6006 | -4.7600 | 0.0187 |
| Rice | -1.6250 | 0.6579 | -2.4700 | 0.1802 |
| Soy | -8.7350 | 0.6579 | -13.2800 | 0.0002 |
| Flour Type = Control subtracted from: | | | | |
| Rice | 1.2320 | 0.6006 | 2.0510 | 0.2845 |
| Soy | -5.8780 | 0.6006 | -9.7870 | 0.0007 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | -7.1100 | 0.6579 | -10.8100 | 0.0005 |

**Table A.12** ANOVA and Tukey Multiple Comparison Test Tables for oil content of coating part of 5min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 46.810 | 46.810 | 15.603 | 15.57 | 0.006 |
| Error | 5 | 5.010 | 5.010 | 1.002 | | |
| Total | 8 | 51.820 | | | | |

Tukey Simultaneous Tests
Response Variable O. Content of Coating %
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -2.4000 | 0.9138 | -2.6260 | 0.1519 |
| Rice | 0.8500 | 1.0010 | 0.8490 | 0.8300 |
| Soy | -5.3500 | 1.0010 | -5.3450 | 0.0115 |
| Flour Type = Control subtracted from: | | | | |
| Rice | 3.2500 | 0.9138 | 3.5570 | 0.0571 |
| Soy | -2.9500 | 0.9138 | -3.2280 | 0.0799 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | -6.2000 | 1.0010 | -6.1940 | 0.0060 |

**Table A.13** ANOVA Table for oil content of coating part of 1.5 min microwave fried and 5 min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Frying Method | 2 | Conventional, Microwave |
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 0.001 | 0.001 | 0.001 | 0.00 | 0.982 |
| Flour Type | 3 | 125.446 | 125.446 | 41.815 | 34.61 | 0.000 |
| Error | 13 | 15.708 | 15.708 | 1.208 | | |
| Total | 17 | 141.155 | | | | |

**Table A.14** ANOVA and Tukey Multiple Comparison Test Tables for CIE L values of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 103.148 | 103.148 | 34.383 | 4.06 | 0.044 |
| Frying Time | 3 | 329.289 | 329.289 | 109.763 | 12.97 | 0.001 |
| Error | 9 | 76.180 | 76.180 | 8.464 | | |
| Total | 15 | 508.617 | | | | |

Tukey Simultaneous Tests
Response Variable
Color
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -1.5250 | 2.0570 | -0.7413 | 0.8781 |
| Rice | -0.6630 | 2.0570 | -0.3220 | 0.9877 |
| Soy | 5.0000 | 2.0570 | 2.4304 | 0.1401 |
| Flour Type = Control subtracted from: | | | | |
| Rice | 0.8625 | 2.0570 | 0.4193 | 0.9738 |
| Soy | 6.5250 | 2.0570 | 3.1717 | 0.0464 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | 5.6630 | 2.0570 | 2.7520 | 0.0871 |

**Table A.15** ANOVA and Tukey Multiple Comparison Test Tables for CIE a values of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 58.595 | 58.595 | 19.532 | 32.04 | 0.000 |
| Frying Time | 3 | 90.480 | 90.480 | 30.160 | 49.48 | 0.000 |
| Error | 9 | 5.486 | 5.486 | 0.610 | | |
| Total | 15 | 154.562 | | | | |

Tukey Simultaneous Tests
Response Variable
Color
All Pairwise Comparisons among Levels of Flour Types

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Flour Type = Chickpea subtracted from | | | | |
| Control | 1.2120 | 0.5521 | 2.1960 | 0.1959 |
| Rice | -0.0500 | 0.5521 | -0.0910 | 0.9997 |
| Soy | -3.8750 | 0.5521 | -7.0190 | 0.0003 |
| Flour Type = Control subtracted from: | | | | |
| Rice | -1.2620 | 0.5521 | -2.2870 | 0.1723 |
| Soy | -5.0870 | 0.5521 | -9.2150 | 0.0000 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | -3.8250 | 0.5521 | -6.9280 | 0.0003 |

**Table A.16** ANOVA and Tukey Multiple Comparison Test Tables for CIE b values of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 5.175 | 5.175 | 1.725 | 0.27 | 0.848 |
| Frying Time | 3 | 492.356 | 492.356 | 164.119 | 25.35 | 0.000 |
| Error | 9 | 58.274 | 58.274 | 6.475 | | |
| Total | 15 | 555.805 | | | | |

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

Frying Time = 0.5min subtracted from

| Frying Time | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| 1.0 min | -3.8300 | 1.7990 | -2.1260 | 0.2161 |
| 1.5 min | -9.5400 | 1.7990 | -5.3010 | 0.0023 |
| 2.0 min | -14.590 | 1.7990 | -8.1070 | 0.0001 |

Frying Time = 1.0min subtracted from:

| Frying Time | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| 1.5 min | -5.7100 | 1.7990 | -3.1750 | 0.0462 |
| 2.0 min | -10.760 | 1.7990 | -5.9820 | 0.0010 |

Frying Time = 1.5min subtracted from:

| Frying Time | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| 2.0 min | -5.0500 | 1.7990 | -2.8070 | 0.0803 |

**Table A.17** ANOVA and Tukey Multiple Comparison Test Tables for CIE L values of 1.5 min microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 134.375 | 134.375 | 44.792 | 199.07 | 0.000 |
| Error | 4 | 0.900 | 0.900 | 0.225 | | |
| Total | 7 | 135.275 | | | | |

Tukey Simultaneous Tests
Response Variable Color
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -0.9000 | | -1.8970 | 0.3552 |
| Rice | -0.7000 | | -1.4760 | 0.5242 |
| Soy | 8.9000 | | 18.7630 | 0.0002 |
| Flour Type = Control subtracted from: | | | | |
| Rice | 0.2000 | | 0.4216 | 0.9717 |
| Soy | 9.8000 | | 20.6602 | 0.0001 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | 9.6000 | 0.4743 | 20.2400 | 0.0001 |

**Table A.18** ANOVA and Tukey Multiple Comparison Test Tables for CIE a values of 1.5 min microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 41.414 | 41.414 | 13.805 | 225.38 | 0.000 |
| Error | 4 | 0.245 | 0.245 | 0.061 | | |
| Total | 7 | 41.659 | | | | |

Tukey Simultaneous Tests
Response Variable Color
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | 0.2500 | | 1.0100 | 0.7536 |
| Rice | 0.0500 | | 0.2000 | 0.9966 |
| Soy | -5.1500 | | -20.8100 | 0.0001 |

Flour Type = Control subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Rice | -0.2000 | | -0.8100 | 0.8483 |
| Soy | -5.4000 | | -21.8200 | 0.0001 |

Flour Type = Rice subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Soy | -5.2000 | | -21.0100 | 0.0001 |

**Table A.19** ANOVA and Tukey Multiple Comparison Test Tables for CIE L values of 5min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 32.425 | 32.425 | 10.808 | 14.27 | 0.013 |
| Error | 4 | 3.030 | 3.030 | 0.758 | | |
| Total | 7 | 35.455 | | | | |

Tukey Simultaneous Tests
Response Variable Color
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | -4.1000 | 0.8703 | -4.7110 | 0.0309 |
| Rice | -0.5500 | 0.8703 | -0.6320 | 0.9166 |
| Soy | 1.3500 | 0.8703 | 1.5510 | 0.4903 |

Flour Type = Control subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Rice | 3.5500 | 0.8703 | 4.0790 | 0.0497 |
| Soy | 5.4500 | 0.8703 | 6.2620 | 0.0114 |

Flour Type = Rice subtracted from:

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Soy | 1.9000 | 0.8703 | 2.1830 | 0.2698 |

**Table A.20** ANOVA and Tukey Multiple Comparison Test Tables for CIE a values of 5min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 2.094 | 2.094 | 0.698 | 5.64 | 0.064 |
| Error | 4 | 0.495 | 0.495 | 0.124 | | |
| Total | 7 | 2.589 | | | | |

Tukey Simultaneous Tests
Response Variable Color
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | 0.3500 | 0.3518 | 0.9949 | 0.7611 |
| Rice | 1.2000 | 0.3518 | 3.4112 | 0.0863 |
| Soy | -0.1000 | 0.3518 | -0.2843 | 0.9908 |
| Flour Type = Control subtracted from: | | | | |
| Rice | 0.8500 | 0.3518 | 2.4160 | 0.2154 |
| Soy | -0.4500 | 0.3518 | -1.2790 | 0.6185 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | -1.3000 | 0.3518 | -3.6950 | 0.0678 |

**Table A.21** ANOVA and Tukey Multiple Comparison Test Tables for CIE b values of 5min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 10.714 | 10.714 | 3.571 | 12.93 | 0.016 |
| Error | 4 | 1.105 | 1.105 | 0.276 | | |
| Total | 7 | 11.819 | | | | |

Tukey Simultaneous Tests

Response Variable Color

All Pairwise Comparisons among Levels of Flour Types

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Flour Type = Chickpea subtracted from | | | | |
| Control | -3.0000 | 0.5256 | -5.7080 | 0.0159 |
| Rice | -0.5500 | 0.5256 | -1.0460 | 0.7355 |
| Soy | -0.6000 | 0.5256 | -1.1420 | 0.6876 |
| Flour Type = Control subtracted from: | | | | |
| Rice | 2.4500 | 0.5256 | 4.6610 | 0.0320 |
| Soy | 2.4000 | 0.5256 | 4.5660 | 0.0343 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | -0.0500 | 0.5256 | -0.0951 | 0.9996 |

**Table A.22** ANOVA Table for CIE L values of 1.5 min microwave fried and 5 min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Frying Method | 2 | Conventional, Microwave |
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 268.960 | 268.960 | 268.960 | 68.64 | 0.000 |
| Flour Type | 3 | 127.625 | 127.625 | 42.542 | 10.86 | 0.001 |
| Error | 11 | 43.105 | 43.105 | 3.919 | | |
| Total | 15 | 439.690 | | | | |

**Table A.23** ANOVA Table for CIE a values of 1.5 min microwave fried and 5 min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Frying Method | 2 | Conventional, Microwave |
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 7.563 | 7.563 | 7.563 | 4.71 | 0.053 |
| Flour Type | 3 | 26.595 | 26.595 | 8.865 | 5.52 | 0.015 |
| Error | 11 | 17.653 | 17.653 | 1.605 | | |
| Total | 15 | 51.810 | | | | |

**Table A.24** ANOVA Table for CIE b values of 1.5 min microwave fried and 5 min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Frying Method | 2 | Conventional, Microwave |
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 314.176 | 314.176 | 314.176 | 203.51 | 0.000 |
| Flour Type | 3 | 3.132 | 3.132 | 1.044 | 0.68 | 0.584 |
| Error | 11 | 16.982 | 16.982 | 1.544 | | |
| Total | 15 | 334.289 | | | | |

**Table A.25** ANOVA and Tukey Multiple Comparison Test Tables for specific bulk volume values of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 0.072 | 0.065 | 0.022 | 1.93 | 0.137 |
| Frying Time | 3 | 1.293 | 1.293 | 0.431 | 38.29 | 0.000 |
| Error | 47 | 0.529 | 0.529 | 0.011 | | |
| Total | 53 | 1.895 | | | | |

Tukey Simultaneous Tests
Response Variable Specific Bulk Volume
All Pairwise Comparisons among Levels of Frying Time

Frying Time = 0.5min subtracted from

| Frying Time | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| 1.0 min | 0.2181 | 0.0389 | 5.6120 | 0.0000 |
| 1.5 min | 0.2854 | 0.0413 | 6.9090 | 0.0000 |
| 2.0 min | 0.4284 | 0.0412 | 10.4110 | 0.0000 |
| Frying Time = 1.0min subtracted from: | | | | |
| 1.5 min | 0.0673 | 0.0413 | 1.6290 | 0.3725 |
| 2.0 min | 0.2104 | 0.0413 | 5.0950 | 0.0000 |
| Frying Time = 1.5min subtracted from: | | | | |
| 2.0 min | 0.1431 | 0.0435 | 3.2920 | 0.0099 |

**Table A.26** ANOVA and Tukey Multiple Comparison Test Tables for porosity values of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 0.009 | 0.009 | 0.003 | 3.08 | 0.046 |
| Frying Time | 3 | 0.142 | 0.142 | 0.047 | 46.77 | 0.000 |
| Error | 25 | 0.025 | 0.025 | 0.001 | | |
| Total | 31 | 0.177 | | | | |

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

Frying Time = 0.5min subtracted from

| Frying Time | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| 1.0 min | 0.1025 | 0.0159 | 6.4370 | 0.0000 |
| 1.5 min | 0.1438 | 0.0159 | 9.0280 | 0.0000 |
| 2.0 min | 0.1775 | 0.0159 | 11.1480 | 0.0000 |
| Frying Time = 1.0min subtracted from: | | | | |
| 1.5 min | 0.0413 | 0.0159 | 2.5910 | 0.0701 |
| 2.0 min | 0.0750 | 0.0159 | 4.7100 | 0.0004 |
| Frying Time = 1.5min subtracted from: | | | | |
| 2.0 min | 0.0338 | 0.0159 | 2.1200 | 0.1745 |

**Table A.27** ANOVA and Tukey Multiple Comparison Test Tables for hardness values of microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Time | 4 | 0.5, 1.0, 1.5, 2.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 80.594 | 78.053 | 26.018 | 59.11 | 0.000 |
| Frying Time | 3 | 52.295 | 52.295 | 17.432 | 39.60 | 0.000 |
| Error | 113 | 49.741 | 49.741 | 0.440 | | |
| Total | 119 | 182.630 | | | | |

Tukey Simultaneous Tests
Response Variable Hardness
All Pairwise Comparisons among Levels of Flour Type

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | 1.8129 | 0.1728 | 10.4900 | 0.0000 |
| Rice | 0.9164 | 0.1710 | 5.3590 | 0.0000 |
| Soy | 0.4748 | 0.1746 | 2.7200 | 0.0375 |
| Flour Type = Control subtracted from: | | | | |
| Rice | -0.8960 | 0.1728 | -5.1890 | 0.0000 |
| Soy | -1.3380 | 0.1762 | -7.5930 | 0.0000 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | -0.4416 | 0.1734 | -2.5470 | 0.0582 |

**Table A.28** ANOVA and Tukey Multiple Comparison Test Tables for hardness values of 1.5 min microwave fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 7.858 | 7.858 | 2.619 | 271.64 | 0.000 |
| Error | 24 | 0.231 | 0.231 | 0.010 | | |
| Total | 27 | 8.090 | | | | |

Tukey Simultaneous Tests

Response Variable Hardness

All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | 1.3571 | 0.0525 | 25.8560 | 0.0000 |
| Rice | 0.9286 | 0.0525 | 17.6910 | 0.0000 |
| Soy | 0.3000 | 0.0525 | 5.7150 | 0.0000 |
| Flour Type = Control subtracted from: | | | | |
| Rice | -0.4290 | 0.0525 | -8.1600 | 0.0000 |
| Soy | -1.0570 | 0.0525 | -20.1400 | 0.0000 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | -0.6286 | 0.0525 | -11.9800 | 0.0000 |

**Table A.29** ANOVA and Tukey Multiple Comparison Test Tables for hardness values of 5min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 1.676 | 1.676 | 0.559 | 29.7 | 0.000 |
| Error | 24 | 0.451 | 0.451 | 0.019 | | |
| Total | 27 | 2.127 | | | | |

Tukey Simultaneous Tests
Response Variable Hardness
All Pairwise Comparisons among Levels of Flour Types

Flour Type = Chickpea subtracted from

| Flour Type | Difference of Means | SE of Difference | T-Value | Adj. P-Value |
|---|---|---|---|---|
| Control | 0.4714 | 0.0733 | 6.4310 | 0.0000 |
| Rice | 0.0429 | 0.0733 | 0.5850 | 0.9358 |
| Soy | -0.2000 | 0.0733 | -2.7280 | 0.0534 |
| Flour Type = Control subtracted from: | | | | |
| Rice | -0.4286 | 0.0733 | -5.8460 | 0.0000 |
| Soy | -0.6714 | 0.0733 | -9.1590 | 0.0000 |
| Flour Type = Rice subtracted from: | | | | |
| Soy | -0.2429 | 0.0733 | -3.3130 | 0.0145 |

**Table A.30** ANOVA Table for hardness values of 1.5 min microwave fried and 5 min conventionally deep-fat fried chicken fingers with different flour types in their batter formulations

| Factor | Levels | Values |
|---|---|---|
| Frying Method | 2 | Conventional, Microwave |
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 1.969 | 1.969 | 1.969 | 39.61 | 0.000 |
| Flour Type | 3 | 7.682 | 7.682 | 2.561 | 51.52 | 0.000 |
| Error | 51 | 2.535 | 2.535 | 0.050 | | |
| Total | 55 | 12.186 | | | | |

**Table A.31** ANOVA Table for acrylamide contents of microwave fried samples having similar moisture contents

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 441.000 | 441.000 | 147.000 | 0.1 | 0.954 |
| Error | 4 | 5729.000 | 5729.000 | 1432.000 | | |
| Total | 7 | 6170.000 | | | | |

**Table A.32** ANOVA Table for acrylamide contents of 1.5 min microwave fried and 5 min conventionally deep-fat fried samples

| Factor | Levels | Values |
|---|---|---|
| Flour Type | 4 | Control, Chickpea flour, Rice flour, Soy flour |
| Frying Method | 2 | Conventional, Microwave |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Flour Type | 3 | 176.010 | 176.010 | 58.670 | 0.95 | 0.517 |
| Frying Method | 1 | 1371.610 | 1371.610 | 1371.610 | 22.17 | 0.018 |
| Error | 3 | 185.610 | 185.610 | 61.870 | | |
| Total | 7 | 1733.230 | | | | |

**Table A.33** ANOVA Table for mean values of histograms from the temperature maps of conventionally deep-fat fried chicken fingers at 1 min of holding time

| Factor | Levels | Values |
|---|---|---|
| Slice | 3 | Slice 1, Slice 2, Slice 3 |
| Frying Time | 2 | 2.0, 5.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Time | 1 | 203.280 | 203.280 | 203.280 | 31.81 | 0.000 |
| Slice | 2 | 14.505 | 14.505 | 7.253 | 1.13 | 0.349 |
| Error | 14 | 89.470 | 89.470 | 6.391 | | |
| Total | 17 | 307.255 | | | | |

**Table A.34** ANOVA Table for standard deviation of histograms from the temperature maps of conventionally deep-fat fried chicken fingers at 1 min of holding time

| Factor | Levels | Values |
|---|---|---|
| Slice | 3 | Slice 1, Slice 2, Slice 3 |
| Frying Time | 2 | 2.0, 5.0 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Time | 1 | 24.542 | 24.542 | 24.542 | 11.88 | 0.004 |
| Slice | 2 | 1.919 | 1.919 | 0.959 | 0.46 | 0.638 |
| Error | 14 | 28.928 | 28.928 | 2.066 | | |
| Total | 17 | 55.389 | | | | |

**Table A.35** ANOVA Table for mean values of histograms from the temperature maps of 0.5 min microwave fried and 2 min conventionally deep-fat fried chicken fingers at 1 min of holding time

| Factor | Levels | Values |
|---|---|---|
| Slice | 3 | Slice 1, Slice 2, Slice 3 |
| Frying Method | 2 | Conventional, Microwave |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 16.500 | 16.500 | 16.500 | 19.62 | 0.051 |
| Slice | 2 | 9.308 | 9.308 | 4.654 | 5.53 | 0.153 |
| Error | 2 | 1.682 | 1.682 | 0.841 | | |
| Total | 5 | 27.491 | | | | |

**Table A.36** ANOVA Table for mean values of histograms from the temperature maps of microwave fried chicken fingers at 1 min of holding time

| Factor | Levels | Values |
|---|---|---|
| Slice | 3 | Slice 1, Slice 2, Slice 3 |
| Frying Time | 2 | 0.5, 1.5 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Time | 1 | 20.182 | 20.182 | 20.182 | 9.29 | 0.009 |
| Slice | 2 | 27.015 | 27.015 | 13.507 | 6.22 | 0.012 |
| Error | 14 | 30.401 | 30.401 | 2.171 | | |
| Total | 17 | 77.598 | | | | |

**Table A.37** ANOVA Table for standard deviation of histograms from the temperature maps of microwave fried chicken fingers at 1 min of holding time

| Factor | Levels | Values |
|---|---|---|
| Slice | 3 | Slice 1, Slice 2, Slice 3 |
| Frying Time | 2 | 0.5, 1.5 |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Time | 1 | 142.383 | 142.383 | 142.383 | 58.63 | 0.000 |
| Slice | 2 | 1.258 | 1.258 | 0.629 | 0.26 | 0.775 |
| Error | 14 | 33.999 | 33.999 | 2.428 | | |
| Total | 17 | 177.640 | | | | |

**Table A.38** ANOVA Table for standard deviation of histograms from the temperature maps of 1.5 min microwave fried and 5 min conventionally deep-fat fried chicken fingers at 1 min of holding time

| Factor | Levels | Values |
|---|---|---|
| Slice | 3 | Slice 1, Slice 2, Slice 3 |
| Frying Method | 2 | Conventional, Microwave |

| Source | DF | Seq SS | Adj.SS | Adj. MS | F | p |
|---|---|---|---|---|---|---|
| Frying Method | 1 | 6.917 | 6.917 | 6.917 | 96.47 | 0.010 |
| Slice | 2 | 1.169 | 1.169 | 0.585 | 8.15 | 0.109 |
| Error | 2 | 0.143 | 0.143 | 0.072 | | |
| Total | 5 | 8.229 | | | | |

# CURRICULUM VITAE

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| 2002-Present | METU Food Engineering | Teaching Assistant |
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## FOREIGN LANGUAGES

Advanced English

## PUBLICATIONS

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1. Barutcu, I., Sahin, S., & Sumnu, G., 2009. Effects of microwave frying and different flour types addition on the microstructure of batter coatings. Journal of Food Engineering, 95: 684-692.

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1. Barutcu, I., Sahin, S., & Sumnu, G., 2007. Effects of batters containing different types of flours on quality of microwave fried chicken fingers. 2007 CIGR Section VI International Symposium on Food and Agricultural Products: Processing and Innovations, Naples, Italy, p.138.
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