Effects of Two Proteins from Whey as an Oil Barrier in the Production of Deep-Fried Chicken

A thesis presented to
the faculty of
the College of Health Sciences and Professions of Ohio University

In partial fulfillment
of the requirements for the degree
Master of Science

Simin Yuan
December 2012

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This thesis titled
Effects of Two Proteins from Whey as an Oil Barrier in the Production of Deep-Fried
Chicken

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Abstract

YUAN, SIMIN, M.S., December 2012, Food and Nutrition Sciences

Effects of Two Proteins from Whey as an Oil Barrier in the Production of Deep-Fried Chicken

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Obesity has become common in the United States population. Due to this, consumers may pay more attention to cutting caloric intake. Producing low-fat, deep-fried chicken has been investigated in different ways. A previous study showed that whey protein isolate (WPI), when applied as a 10% solution after breading, inhibited oil absorption in fried chicken patties by as much as 37%. WPI consists primarily of the proteins β-lactoglobulin (β-lg, 50-55%) and α-lactalbumin (α-la, 20-25%). The objective of this thesis was to improve a treatment to reduce oil absorption in fully fried, battered, and breaded chicken using solutions containing WPI, α-la and β-lg. When applied as a prefrying dip at 10%, WPI and β-lg were successful in reducing the lipid content compared to the undipped control group. There were three different ratios of β-lg/α-la combinations studied in the research. After analyzing the lipid content, moisture content, coating pickup, surface color, and some texture attributes, the effectiveness of WPI as an oil barrier was confirmed. The application of WPI, α-la and β-lg did not have much effect on the other characteristics of the chicken samples. It is likely that β-lg is the dominant protein involved in oil inhibition, but α-la may have a small role. Processing may enhance the oil inhibiting properties of β-lg, such as thermal gelation.
Dedication

My dear parents, Sansi Yuan and Min Zhang.

Who are the sunshine in my life

My boyfriend, Yinglei Pei.

Who plays such an important role along the journey.
Acknowledgments

I would like to express my sincere gratitude for the following amazing individuals who have supported me directly and indirectly throughout my M. S. studies and in the production of this thesis. Your support helped me experience a wonderful time growing up and becoming the person I am. Thank you so much.

Dr. Robert G. Brannan
Dr. Michael R. Kushnick
Francis McFadden
Gai Wang
Andrew Myers
Xingbo Liu
Yating Liu
Camille Mihalic
Dr. Darlene Berryman
Dr. David Holben
Xiaowei Zhu
Sijie Wang
Deb Murray
Huijiaqi Wang
Mark Riley

Everyone at Davisco Foods International and Jones-Hamilton Co.

All my other friends, classmates, and professors at Ohio University
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Chapter 1: Introduction

This research investigated the effectiveness of two proteins from whey as an oil barrier to reduce the lipid content of deep-fried, battered and breaded chicken breast pieces. These proteins were applied as a post-breading dip before frying. The oil barrier is beneficial because it produces lower fat fried chicken.

An American Heart Association (AHA) statistical fact sheet shows that there are 74.3 million overweight (body mass index [BMI] ≥25.0 kg/m2) and 75.0 million obese (BMI ≥30.0 kg/m2) people age 20 and older, about 48% of the U.S. population (AHA, 2012). Similar to the adult prevalence of being overweight or obese, about 1 in 3 children ages 2-19 have BMI-for-age at or above the 85th percentile of the 2000 Centers for Disease Control and Prevention (CDC) growth charts (CDC, 2002). AHA also indicates that these children have a 70% chance to be obese as adults.

Obesity is closely related to many chronic diseases, including coronary heart disease (CHD), stroke, and diabetes mellitus (Maksimovic, Vlajinac, Radak, Marinkovic, & Jorga, 2012). These chronic diseases are the major causes of mortality and morbidity worldwide, particularly in Westernized countries. The worldwide obesity epidemic and the ensuing comorbidities not only threaten individual health and longevity, but also place financial burdens on industry and the public (Schmid, Schneider, Golay, & Keller, 2005). For instance, the total cost to society of adolescent overweight and obesity has increased to $254 billion. Of this total, $208 billion was used in lost productivity secondary to premature morbidity and mortality and $46 billion in direct medical costs, such as cardiac revascularization and diagnostic cardiac catheterization. It is estimated
that the total healthcare costs attributable to obesity could reach $861 to $957 billion by 2030 if the current trends continue (AHA, 2012). Therefore, obesity threatens the quality of life as well as drops production capacity in society.

The high calorie consumption, especially the high-fat diet, plays an important role for the trends above. The aggregate food supply in 2000 provided 3,800 calories per person per day, 500 calories above the 1970 level and 800 calories above the record low in 1957 and 1958. Added fats and oils contributed 9.0 percentage points to the increase (U.S. Department of Agriculture [USDA], 2008). Some of the observed increase in caloric intake may be associated with an increase in eating outside of the home. One such contribution is the availability of fast food as a cheap, convenient, and popular foodservice option all around the world. As an example of fried food provided through fast food options include French fries and chicken nuggets which can have as much as 20 percent fat content per serving (Bingol, Zhang, Pan, & McHugh, 2012; Marikkar, Ng, & Man, 2011).

In order to reduce the fat in high-fat fried products, several oil inhibition methods have been used during the frying process, such as fryer selection, frying oil selection, and temperature control (Bouchon, Aguilera, & Pyle, 2003). These methods also decrease the total calorie content. Others have employed edible films via a thermoplastic processing that provides the opportunity to reduce fat from food material. Food proteins, like wheat gluten, corn zein, soy protein, and whey protein, can form a film via it (Hernandez-Izquierdo & Krochta, 2008). Whey protein is a by-product in cheese-making in industry via milk coagulation and removal of the curd. A study using a whey pretreatment to
reduce oil absorption in fully fried, battered, and breaded products showed that whey protein was able to decrease lipid content from the fried chicken (Mah, Price, & Brannan, 2008). Specifically, whey protein isolate (WPI), when applied as a 10% solution after breading, inhibited oil absorption in fried chicken patties by as much as 37.5%. The formation of a thermogel probably plays an essential part in this process. Both beta-lactoglobulin (β-lg) and alpha-lactalbumin (α-la) are the main components of WPI, which comprise about 50% and 25%, respectively. The β-lg is largely responsible for solubility, gelation, foaming, emulsification, and flavor binding. The α-la has been reported to affect the stability and work with fatty acids. Previous research has shown that β-lg caused reduction in oil absorption in boneless chicken patties (21%) and bone-in chicken thighs (27%) (Brannan, Mah, Schott, & Myers, 2009). However, this work did not compare and contrast β-lg, α-la, and WPI in coating to each other. What is not known is whether the reduction observed by WPI can be attributed to either α-la or β-lg.

**Statement of the Problem**

The objective of this study was to improve a treatment to reduce oil absorption in fully fried, battered, and breaded chicken via solutions containing WPI, α-la and β-lg. Whey protein is soluble in water. Therefore, α-la and β-lg can work as a dip, too. As the two main components in whey protein, they may have some oil barrier properties. For example, α-la has the ability to bind metal cations and interacts with fatty acids. The β-lg has free sulfhydryl groups available to form insoluble films during frying and it is thermally sensitive, which helps it build a gel film quickly. These characteristics may be beneficial to improve the application of whey protein or its components to work as
coatings to reduce fat for fried-food products. This research focuses on the determination of the effectiveness of α-la and β-lg solution compared to WPI when used as postbreading dips for deep-fried chicken.

Research Questions

1. What is the effect of different concentrations of α-lactalbumin and β-lactoglobulin, when applied as post-breading dips, to reduce oil absorption in deep-fried battered and breaded chicken?

2. How does different concentrations of α-lactalbumin and β-lactoglobulin, applied as post-breading dips, affect quality parameters of the battered and breaded chicken?

Significance of Study

Whey protein has been used as a nutritional supplement for many years and its acceptability is established among customers (Jost, Maire, Maynard, & Secretin, 2000). Research has shown that WPI is effective in improving food quality, and whey protein improved the appearance of food materials (Lin & Krochta, 2006). Whey also prevented the loss of tensile, barrier and appearance properties (Dangaran & Krochta, 2007). Mah et al. (2008) produced a more nutritional fried food using WPI to reduce fat content for deep-fried chicken (Mah, et al., 2008). Their study determined that the application of WPI as an oil barrier could produce low-fat fried chicken under certain conditions.

Application of either the whey protein or its components as an oil barrier can increase the value of this byproduct of cheese production, as well as the economy of the milk processing industry. Moreover, if this treatment can reduce the lipid content without
changing the sensory characteristics of the fried food, it may be acceptable to people who enjoy relatively lower fat food. If successful, the results of the present study may help to improve many foods that contribute to obesity and therefore many chronic diseases.

**Limitations**

Variations in the frying parameters, e.g. the frying time, pH, and temperature, might have an effect on oil absorption (Tsuzuki, Matsuoka, & Ushida, 2010). Although four replications were employed to maintain the consistency of the data, handmade sample preparation may create the differences in the experiment.

The protein material used was in powder form. Both α-lactalbumin and β-lactoglobulin were pure powders before they were dissolved into water. In this experiment, the highest protein concentration utilized was 10%. Although the protein powder was added slowly and stirred thoroughly, the appearance of foam implied that the ideal concentration of protein in solution might not have been achieved.

From the point of the experimental material, the chicken pieces we used were obtained from the chicken breast called tenderloin. Unlike another popular fried chicken product, chicken nuggets, which can be fabricated from a combination of chicken meat, vegetable protein, gum and a proportion of chicken skin, tenderloin consists of more lean meat (Marikkar et al., 2011). Therefore, caution should be taken when this treatment is directly applied to other fried foods like French fries, fried vegetables, or fried cheese.

**Definition of Terms**

*α-lactalbumin*. The globular protein which composes 20-25% of whey protein, its isoelectric point is between 4.2 and 4.5.
Allergenicity. Relating to or having the effect of an allergen.

β-lactoglobulin. The globular protein which composes 50-55% of whey protein, its isoelectric point is about 5.1.

Deep-frying. The fried material is immersed into hot frying medium.

Edible film. Edible stuff coats the food material, the ingredients of which are included in Generally Recognized as Safe (GRAS) by the Food and Drug Administration (FDA).

Gel. The disperse phase combines with the dispersion medium to produce a substantially dilute cross-linked system.

Gluten. A mixture of insoluble plant proteins used as an adhesive and as a flour substitute, it is found in cereal grains, chiefly corn, and wheat.

Hydrocolloid. A gelatinous colloid in which water is the dispersion material.

Isoelectric point. pH at which protein molecules have no net charge and are least soluble.

Low-fat. Contains less than 3 g fat and contributes less than 30% of calories from fat per serving.

Oil absorption. Under certain processing, the oil used for cooking comes into the food material.

Par-frying. Partially frying food without browning the crust, the fried material has an internal temperature of 71 °C.

Thermal gelation. The food material becomes a gel induced by heat.
Whey protein isolate. The isolate of the soluble protein of milk remaining after milk coagulation and removal of the curd, the protein concentration is over 90%, by weight.

List of Abbreviations and Acronyms

ANOVA. Analysis of Variance

α-la. α-Lactalbumin

β-lg. β-Lactoglobulin

ISP. Isoelectric point

PUFA. Polyunsaturated fatty acids

SAs. sulfonamides

TFAs. trans fatty acids

WPI. Whey protein isolate
Chapter 2: Literature Review

Introduction to Fried Food

Consumption and impact of fried food. Nowadays, Americans are consuming more calories than they consumed 30 years ago. Total caloric intake on a per capita basis for Americans increased from 2,172 calories per day in 1970 to 2,775 calories per day in 2007—an additional 603 calories (USDA, 2008). The fat consumption increased by 24.5 percent, which was about 530 calories, between 1970 and 2000 (USDA, 2008). Specifically, 9% of this increase came from added fats and oils, which improved the taste or nutrition of the food. The total increase in consumption of fats and oils is shown in Table 1. Annual average added fat and oils in 2000 was 67% above that in the 1950-1959. Part of it, like margarine and shortening, came from commercially prepared foods. Wells and Buzby (2008) reported that this portion increased to 86 pounds per person in 2005, compared with 53 pounds per person in 1970.
Table 1

*Average Consumption of Added Fats and Oils Between 1950-59 and 2000 (Annual Average)*

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<tr>
<td>Total added fats and oils</td>
<td>44.6</td>
<td>47.8</td>
<td>53.4</td>
<td>60.8</td>
<td>65.5</td>
<td>74.5</td>
</tr>
<tr>
<td>Salad and cooking oils</td>
<td>9.8</td>
<td>13.9</td>
<td>20.2</td>
<td>25.0</td>
<td>28.2</td>
<td>35.2</td>
</tr>
<tr>
<td>Baking and frying fats</td>
<td>21.4</td>
<td>20.7</td>
<td>20.5</td>
<td>23.6</td>
<td>26.2</td>
<td>29.0</td>
</tr>
<tr>
<td>(shorting, lard and beef tallow)</td>
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<td></td>
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<td></td>
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<tr>
<td>Table spreads (butter and margarine)</td>
<td>17.0</td>
<td>16.5</td>
<td>15.9</td>
<td>15.3</td>
<td>14.0</td>
<td>12.8</td>
</tr>
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1. Total added fats and oils on a fat-content basis. Individual items are a product-weight basis.
2. Salad and cooking oils includes a small amount of specialty fats used mainly in confectionery products and nondairy creamers.
3. Total may not be exact due to rounding.
4. Direct use; excludes use in margarine or shortening.


As a combination of fast food outlets, quick/fast-casual dinings, full-service restaurants, home delivery/take-away outlets, and institutional foodservices (healthcare, schools, colleges/universities), away-from-home food industry increased its proportion in food consumption quickly. The total expenditures away-from-home food in the United
States increased from 4,121 million dollars in 1929 to 594,269 in 2010. Away-from-home food refers to food prepared and purchased outside of the home (USDA, 2011). In the United States, with approximately 1/3 of daily calorie consumption coming from away-from home foods, it is important to consider how individuals can fit these items into a healthy eating plan (CDC, 2006). Data from the USDA’s food intake surveys show that away-from-home food provided 32 percent of total food energy consumption in 1994-1996, increased from 18 percent in 1977-1978. The data also show that, in the case of eating out, people are more likely either to eat more or eat higher calorie foods—or both—and that this tendency appears to be increasing.

As a convenience product, high-fat fried food, which contains not less than 20g of fat of 100g solid food, is a popular part of the American diet (Arambepola, Scarborough, Boxer, & Rayner, 2009). However, nutritionists consider high-fat foods to be detrimental to one’s health when they are not eaten in moderation as part of a well-balanced diet. When fried foods are consumed, people are less likely to eat whole grains, fruits, and vegetable. The latter are associated with lower blood cholesterol and sugar levels and improved digestive function. Based on the USDA’s Dietary Guidelines, Americans should keep total fat consumption between 20 and 35 percent of daily energy intake (Otten, Hellwig, & Meyers, 2006). From 1950 to 1999, the fats and oils group’s contribution to the diet increased 12% to 53% of total calories. Part of this increase is likely due to the increase in consumption of high-fat snack foods and the higher consumption of fried foods in foodservice outlets (Lin, Frazao, & Guthrie, 1999).
Affected by eating habits of adults, the prevalence of being overweight among adolescents and children increased substantially from 1999 to 2004 to approximately 17% in the U.S. Several research groups demonstrated one of the major causes of obesity is the change in diet, in terms of quantity and quality, which has become more “Westernized” (Cordain et al., 2005). The Western diet is characterized by a high intake of red and processed meats as well as refined foods. These foods increase the calorie uptake (Qi, Cornelis, Zhang, van Dam, & Hu, 2009). From 1980 to 2004, the obesity population in U.S. adults has doubled. Of the 22.5 million adults in the United States in 2007, 74.7 million (33%) were overweight (body mass index [BMI]: 25.0–29.9). Nearly 34% are obese (BMI ≥30.0), of whom nearly 6% are extremely obese (BMI ≥40.0) (Ogden et al., 2006). With the obesity prevalence increasing, approximately two thirds of U.S. adults and one fifth of U.S. children were reported either obese or overweight by the end of 2006 (Khan et al., 2009). In the past decade, chronic diseases, such as cardiovascular diseases (CVD), which include coronary heart disease (CHD) and stroke, and diabetes mellitus have become the major causes of mortality and morbidity worldwide, especially in Westernized countries. The estimated annual medical expenditures, which are associated with eliminating overweight and obesity among adults, are around $169 billion, which is equivalent to approximately 9% of total national health care expenditures (Dall et al., 2009).

**Industrial processing of fried food.** Frying remains one of the most widely used methods of preparing food. Fried foods are convenient for food service operators to serve their customers within 3 to 4 minutes (Gupta, Warner, & White, 2004). Due to their
unique characteristics, breaded fried foods are popular in the food market. They are able to contain crispy exteriors and juicy interiors, which contribute to customers’ satisfaction. They are also economical. Sasiela indicated that the cost of the final product can be reduced by 20 to 30% by adding breading and batters during processing (Sasiela, 2004).

A normal industry frying process includes battering, breading, frying, freezing and packaging (Mallikarjunan, Ngadi, & Chinna, 2009). Sometimes a predust is added before battering. Following is a schematic flow diagram of a typical industrial frying process (see Figure 1).

---

**Figure 1.** A schematic flow in a typical industrial frying process. Food materials are transported between different machines in this order: predusting, battering, breading, frying, freezing, and packaging.
**Prefrying coating.** Though predusting is an optional process for many products, it can provide the first coating for food materials. Flour is often used as a main ingredient for predusting. Flour can offer viscosity and promote more adhesion when gluten forms. In some cases, food companies use flour which contains reducing sugars when frying contributed to coat color and flavor properties through Maillard reaction (Mohamed, Norhasimah, & Mansoor, 1998). As the most typical flour used, wheat flour significantly improves adhesion and enhances the appearance of different kinds of the fried food. At the same time, its film-forming properties reduce moisture loss and promote an appetizing and crisp surface (CDC, 2006).

By acting as carriers for a variety of seasonings and spices, batters become an essential part of prefrying processing. Batter is defined as a thick liquid dough but pourable mixture, which consists of flour or starch blended with water into which a product is dipped before being breaded and fried (Mallikarjunan et al., 2009). Added before breading, batters form a base for the breading to adhere to the product. Loewe (1993) classified batters into two groups: interface/adhesion batters and puff/tempura batters. Interface/adhesion batters are usually formed with starch, which makes batters have an optimum viscosity (Olewnik & Kulp, 1993). Puff/tempura batters depend on chemical leavening agents. These agents produce visual and structural qualities for this system (CDC, 2006). Batters can offer cohesion for the coating system. With certain viscosity, batters built a matrix to hold other useful ingredients for the food material (Tavera-Quiroz, Urriza, Pinotti, & Bertola, 2012; Yano, 2012). With the various needs of
customers, batters are added with other ingredients, such as gums, seasonings, and egg. For this reason, batters perform other sophisticated and wide applications, including a part of fried meat coating.

Breadings are made in a variety of colors and sizes, and with a variety of ingredients, which determine the performance of different final products. Breadings mainly consist of crumbs, starches, flours, seasonings (Suderman, 1993). Japanese or Panko breadcrumbs are widely used in the fried-food industry. They are produced via ohmic heating, an advanced thermal processing passes electricity through food material resulting in rapid and uniform heating (Moraveji, Ghaderi, & Davarnejad, 2011). Japanese breadcrumbs’ light flake-like appearance comes from induction and resistance heating, which supplies a crispy but not hard texture. This porous structure also creates an elongated shape, as well as strong visual appeal. For this nonuniform granulation, composed of fine and coarse particles, products must be uniformly coated on both top and bottom with the same ratio of fine and coarse crumbs. Only a special type of machine can be used to prevent breading from grinding up during this process (Mallikarjunan et al., 2009).

Both batters and breading serve some functions as food coatings, like keeping color, adding special flavor, and providing texture characteristics. For example, protein and sugar combine to develop Maillard reaction (Jaeger, Janositz, & Knorr, 2010). Since coating color depends on cooking time, temperature, cooking oil, as well as ingredient composition, Maillard reaction plays an essential role in producing golden brown color as an acceptable coating appearance (Landes & Blackshe, 1971). The final products sustain
high moisture and have low fat content. Reducing fat pickup is meaningful from a nutrition point of view (Mellema, 2003). In addition, the seasoning added into batters and breading affects flavor, which is beneficial for most food companies to develop various products.

**Substrates for fried food.** Substrates for fried food are widely applied in food production. French fries are common, and the quality is affected by the strip size and predrying method (Tajner-Czopek, Figiel, & Carbonell-Barrachina, 2008). Researchers have investigated the presence of hydrocolloid layer on the surface of French fries to promote nutritional and sensory properties (Kowalczyk & Gustaw, 2009). People also consume fried mushrooms, peppers, onions, and other vegetables. Fried cheese, which can be prepared to have variety of shapes and hardness, has been studied for its sensory properties, volatile composition, and nutritional parameters (Cais-Sokolinska & Majcher, 2010; Krbavcic & Baric, 2004).

Meat is a main substrate for fried food. A kind of Mexican food called “Carnitas” is an uncoated deep-fat fried pork meat. A study was conducted to establish the relationship between the quality aspects of the food and the frying medium (Sosa-Morales, Orzuna-Espiritu, & Velez-Ruiz, 2006). Some breaded fish products, such as fish balls, are introduced on customers’ table with special coatings (Kilincceker & Hepsag, 2011). In the United States, breaded fish sticks, fillets and patties are very popular. As one of the most popular meat sources, chicken constitutes about 30% of meat consumption in United States. Chicken has a little lower moisture content, which is
around 70% (Bogosavljevic-Boskovic, Mitrovic, Djokovic, Doskovic, & Djeranovic, 2010; Demby & Cunningham, 1980).

**Frying and freezing.** There are three main types of fryers in industrial production: batch, continuous, and vacuum. Batch fryers have the smallest capacity, and are often used for food service and restaurant-type units. Continuous fryers are popular for large-scale production, and use a direct-heat gas to fire and an insulated hood to convey the food. Vacuum fryers are expensive and not perfect for breaded products, but they can fry high-end market products, such as fruits and vegetables (Gupta, Warner, & White, 2004). Regalado, Perez-Peres, Lara-Cortes, and Garcia-Almendarez (2006) indicated vacuum fryers have the potential to reduce oil content, which may increase their market potential (Regalado et al., 2006). The frying process in food factories is used to produce convenient food materials for food service operators. One industrial process is par-frying, for which products are produced for the fast food market. This process, also known as blanching or half-frying, involves partially frying food without browning the crust (Al-Khusaibi, Gordon, Lovegrove, & Niranjan, 2012). Generally the oil temperature is controlled from 300 °F to 400 °F (150 °C to 200 °C). Frying time lasts within 30–90s.

An important aspect in the food industry is that after cooking is complete, the food can be frozen for storage and transportation. Quick freezing keeps a desirable aesthetic appearance of fried food. Food factories often use -40 °C as the storage temperature. Inadequate freezing and storage can have adverse economic impacts for final products (Mukprasirt, Herald, Boyle, & Boyle, 2001).
Factors Affecting Oil Absorption

During the frying process, physical, chemical and organoleptic properties of food are largely changed. In most programs, the main goal of deep-fat frying is to maintain the food flavor inside a tenderized and crispy crust (Moyano, Rioseco, & Gonzalez, 2002). In particular, oil plays an essential role. Oil absorption during deep fat frying is controlled by parameters including oil quality, frying temperature and time, food composition (e.g., its moisture content, porosity), prefrying treatments (partial drying and blanching), coating and food size and etc. (Garmakhany, Maghsoudlou, Kashaninejad, & Jafari, 2010).

Mechanisms of oil absorption. Frying is a dehydration process for food materials. When this process starts, there is simultaneous heat, moisture and fat transfer happening between the products and frying oil. Principles of heat transfer, moisture transfer, and fat transfer are investigated among food scientists (Belitz & Grosch, 1999; Ngadi, Watts, & Correia, 1997). In particular, the decrease of total yield of the product results from the faster loss of moisture than that of oil uptake (Rice & Gamble, 1989). The relationship between moisture and fat uptake becomes a main point in the analysis of how food absorbs oil. There are four theories that may explain part of this mechanism (Saguy & Dana, 2003; Ziaiifar, Achir, Courtois, Trezzani, & Trystram, 2008).

Surfactant theory of frying. As the frying process progresses, the oil degrades and changes from a pure mixture of triglycerides to a mixture of hundreds of compounds including diglycerides, monoglycerides, free fatty acids, and glycerol. At this moment, water evaporating from the food during frying causes hydrolytic reactions, which produce
surface-active agents and polar compounds like mono- and diglycerides. Some of the degradation compounds reduce the interfacial tension between the oil and the food, act as wetting agents and are also considered surface-active agents. These surfactant formations enhance the contact between the food and the frying oil, resulting in excessive fat absorption (Blumenthal, 1991). In this situation, protein can add or increase a barrier between these active surfactants. In particular, the denaturized protein structure is able to offer more thickness on the surface of food products (Dragich & Krochta, 2010).

**Water escape.** Moisture transfer plays a key role in the interaction between the food material and frying medium. For one thing, heat transfer boils water which bursts cell walls, which forms capillary holes and voids. The rate of vaporization is mainly proportional to the temperature difference between the oil and water. For another, oil can be absorbed into these remaining holes and voids (Vitrac, Dufour, Trystram, & Raoult-Wack, 2002). In general, the more the water that escapes from the food, the more the oil that can be transferred into the product. There is evidence that water loss showed the same increases as oil uptake along with the frying time (Gamble, Rice, & Selman, 1987).

**Capillary pressure.** The typical oil temperature of deep-fat frying is in the range of 300 °F to 400 °F (150 °C to 200 °C). The vaporization of water leaves many holes and voids, which have high capillary pressures (Ziaififar et al., 2008). Another group found that the oil absorption results from this capillary force. When the oil fluid displacement happens in crust pores, surface phenomena, like adhesive intermolecular forces and viscosity, cause a pressure difference between the surface oil layer and crust pores. Based on the Laplace law, which describes the wall tension required to withstand a given
internal fluid pressure increases with the vessel radius, this pressure difference leads the capillary motion (Lazar, Patel, Lang, & Archer, 2011). The smaller the hole is, the higher the capillary pressures are (Moreira, Castell-Perez, & Barrufet, 1999). However, the capillary motion applies the static form with the equilibrium positions of fluids. Pore radii are not so ideal in crust pores. Another limitation focuses on the conditions at the end of frying, which influence the final filling in the pore. In practice, both water and air can come into this area as well as frying oil.

**Cooling phase.** When frying is complete, the food is removed from the fryer and this may contribute to fat absorption. When the product starts to cool, water vapor condensation leads to a subsequent decrease in internal pressure. Oil adhered to the food surface is sucked in due to the consequent “vacuum effect.” Therefore, oil uptake is a surface phenomenon, which involves equilibrium between adhesion and drainage of oil as the food is removed from the oil bath. Because the surface plays such an important role, oil uptake and its distribution are determined by the crust microstructure developed during the frying process (Dall et al., 2009). As far as we are concerned, the protein in coatings has been denaturized during post frying. The denaturized protein gains its gelation, as well as plasticity, to work as a barrier. Also, protein coatings form a rough surface to prevent oil from coming into the empty area. However, whey protein films generally provide poor moisture barriers (Regalado et al., 2006).

In reality, oil absorption during frying probably is due to a combination of these four phenomena. Factors that affect oil absorption may mitigate against one or more of
these. Dana and Saguy’s (2006) review concluded that water, oxygen, high pressure and process during played key roles for this process.

**Frying oil quality as affected by frying time, pH and temperature.** There are several important values that determine the quality of frying oil. The hydrolysis reaction caused by water from frying materials would relate to a rapid deterioration of the frying oil, often producing more polar compounds. Typical oil discarded after being fried represents much deteriorated oil with a polar compound content (PC) of 20.3% or more (Totani, Tateishi, Chiue, & Mori, 2012). With respect to trans fatty acids’ (TFAs) accumulation in the frying oil, hydrolysis might somewhat take part in the isomerisation of the double bonds in unsaturated fatty acids. These findings also demonstrated that low temperature frying (for example at 160 °C) might be preferable not only for less TFAs intake but also for less consumption of deteriorating edible oils (Tsuzuki, Matsuoka, & Ushida, 2010).

The change of frying time and temperature affect oil absorption, as well as some specific ingredients in oil. For example, consumers are exposed to the adverse effect caused by a couple of veterinary residues, including sulfonamides (SAs). In an experiment in University of Putra Malaysia, the temperature factor showed significant reduction (p < 0.05) of SAs concentration. However, it is concluded that time has a greater effect than temperature in reducing SAs concentrations in the deep-frying process. However, under higher temperature and longer time of deep frying, greater weight loss appeared in the chicken meat balls. Furthermore, at some point during the deep-frying process, the moisture in the chicken meat balls leached out. It was replaced quickly by
the frying oil. Researchers suggested that the exchange of moisture and oil could remove SAs from the chicken meat balls (Ismail-Fitry, Jinap, Jamilah, & Saleha, 2008).

Temperature can affect air movement during frying. Gas movement results from convective flow due to the total gas pressure gradient in a dynamic system. In this case, a quick pressure is built up when frying at high temperatures. It can be accompanied by Knudsen diffusion due to the concentration gradient. Knudsen diffusion is the diffusion of molecules moves through very narrow capillary pores (Taguchia, 2010). Because the only transport phenomenon during cooling is oil absorption, this is assumed to be a function of the capillary pressure. Cooling can force the product’s inner temperature towards the surrounding temperature. High temperature frying would lead a more dramatic temperature drop, which results in fewer oil molecules being absorbed into the food. In light of these reasons, foods fried at high temperatures have been observed to have less oil uptake (Yamsaengsung & Moreira, 2002).

The pH value has influence on the percentage range of different kinds of free fatty acids during frying in a chemical laboratory (Tur'yan, Kardash, & Garibyan, 2008). The differences between the frying pH and the isoelectric point (ISP) of the protein on the surface of the food worked on the color parameters. The ISP is the pH wherein a zwitterion or amphoteric molecule has a net electric charge of zero. An experiment showed that fried chicken appeared darker and less yellow at pH 2. Their discussion related the effectiveness of pH on the process of oil absorption for the fried food (Mah & Brannan, 2009).
**Frying oil.** Frying oil quality also has a certain influence on oil absorption and characterizes the organoleptic and nutritive properties of fried food products. Its quality is attributed to formation of oil degradation compounds (high molecular weight polar compounds) which increase the polarity of the frying medium and add flavor and color molecules. Consequently, the oil viscosity increases the amount of oil on the food surface (Orthoefer & Cooper, 1998). On the other hand, the interfacial tension between the food and the oil decreases following the facilitation of oil absorption (Marquez-Ruiz, Dobarganes, & Velasco, 2000).

Lipid content is one of the important quality attributes in fried products. Vegetable oil is the most common frying oil. Its main ingredient is soybean oil (Mallikarjunan et al., 2009) Fried potato products with low lipid content have a hard and unfavorable texture. On the other hand, high oil consumption is not cost effective for manufacturers. Also, products with high oil content are fatty and sometimes tasteless. The high fat content of fried foods is limiting their consumption in the food market, especially for the obese population. Today, consumers are looking for food products with lower oil content. Thus it is important to find ways that can reduce the oil content to a certain level in fried products (Moreira et al., 1999).

**Coating Methods for Reduction of Oil Absorption**

**Nonprotein coating methods.** Food coatings may become a good alternative to reduce oil uptake during frying. The effectiveness of a coating is determined by its mechanical and barrier properties, which are associated with its composition and microstructure and with the characteristics of the substrate (García et al., 2008). Some
soluble materials are dissolved into water, and then become suspensions. When the suspensions are heated by oil, they will build a gel at a temperature above the solute gelation points, which can be considered as a film forming outside the food (García et al., 2008).

As one of the polysaccharides used in edible coatings’ formulation, starch is a natural biopolymer very commonly used to constitute film matrices. Due to its wide growth, its low price in the world market makes it attractive to be used. What's more, it is a good matric to add specific additives, such as sorbic acid and its potassium salt (García et al., 2008).

Cellulose derivatives, including methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC), were introduced to coating research for their ability to exhibit thermal gelation. When cellulose derivative suspensions are heated, they form a gel that reverts to below the gelation temperature, and the original suspension viscosity is recovered. Some researchers who were working with mashed potato balls, reported a reduction, compared to uncoated balls, of 59.0%, 61.4%, and 83.6% in fat uptake for samples coated with corn zein, HPMC and MC films, respectively (Mallikarjunan, Chinnan, Balasubramaniam, & Phillips, 1997). Another related study demonstrated that the chitosan poly (methacrylic acid) nanoparticles tended to occupy the empty spaces in the pores of the HPMC matrix, inducing the collapse of the pores and thereby improving barrier properties and film tensile (De Moura, Avena-Bustillos, McHugh, Krochta, & Mattoso, 2008).
A few kinds of particular gums have been used to coat fried food. For example, compared with regular vacuum-fried products (control samples), banana chips coated with either guar gum or xanthan gum solutions at 1.5% reduced oil absorption by 25.22% and 17.22%, respectively (Sothornvit, 2011). Gellan gum had an effect on gelation properties in meat batter to cause structural change (Totosaus & Pérez-Chabela, 2009). Malva nut gum (purified and crude) was introduced to improve yield and stability of chicken products (Barbut, Somboonpanyakul, Quinton, & Smith, 2009).

A group of European scientists explored addition of hydrocolloids in the papads. Screening of hydrocolloids on the frying quality of black gram papads showed 1.00% gum arabic to give maximum reduction in oil content (Patil, Singhal, & Kulkarni, 2001). Another hydrocolloid used as an edible coating is alginate. Alginate is resistant to solvents, oil and grease and exhibits interesting film-forming properties. Among pectin, sodium alginate and methylcellulose films, the alginate film presented the greatest tensile strength and elongation with the lowest oxygen permeability, which guaranteed that it covered food materials uniformly and would have the least chance of rupturing during processing (Fontes, Ramos, Sivi, & Queiroz, 2011).

**Protein methods.** Protein has some essential properties to be used as an oil barrier. The gelation ability of protein has been noticed by the researchers. The microconformational changes were a result of the protein unfolding and disulfide-linked dimer formation (Halder, Chakraborty, Das, & Bose, 2012). Also, the specific bond points and their globular structure in different protein ingredients had important functions on the protein gelation process (Liang & Subirade, 2012).
Edible films offer the opportunity to effectively control mass transfer among different components in a food system or between the food and its surrounding environment. As a heteropolymer with 20 common amino acids, the diversity of proteins results from an almost limitless number of side-chain amino-acid sequential arrangements. It allows for a wide range of interactions and chemical reactions to take place (Hernandez-Izquierdo & Krochta, 2008b; Johnston, Sepe, Miano, Brannan, & Alderton, 2005). Therefore, protein coatings have many special characteristics. There are some important proteins that have been used as coatings for decreasing oil intake.

**Corn zein.** Zein is the prolamine protein fraction found in corn gluten. The identification is based on its solubility in aqueous alcohol solution. Corn zein in particular has a molecular weight between 18 and 45 kDa and is soluble in 60% to 70% ethanol (Shukla, & Cheryan, 2001). The poor solubility of zein in water is due to its high content of hydrophobic amino acid residues, like leucine, alanine, and proline (Kokini, Cocero, Madeka, & Degraaf, 1994). Zein films are relatively good water vapor barriers compared to other edible films, which makes it have commercial interest.

**Wheat gluten.** Wheat gluten is composed of the water-insoluble prolamine and glutelin protein fractions, also known as gliadin and glutenin, respectively. The molecular weight of gliadin is in the range of 20 to 50 kDa, while glutenin has a larger average molecular weight of 250 kDa. The high molecular weight of glutenin can be attributed to the presence of intermolecular disulfide bonds, joining individual protein chains and resulting in a larger polymer (Kokini et al., 1994; Krochta, 1997). This reaction may work to combine fatty acids during frying.
**Soy protein.** Soy protein fractions include 2S, 7S, 11S, and 15S (Larger Svedberg [S] numbers). The main constituents of soy protein are the 7S (conglycinin) and 11S (glycinin) fractions. The β-conglycinin has a molecular weight of 180 kDa and is rich in asparagine, glutamine, leucine, and arginine residues. Unlike glycinin, which contains 20 intramolecular disulfide bonds, disulfide cross-linking in conglycinin is limited (Khorshid, Hossain, & Farid, 2007). The use of soy protein in the formation of films or coatings on food products has been investigated and it was found that its superior elastic properties could offer more interactive protein strands as a film. Its ability to form edible films adds value to soybeans (Jiang, Chen, & Xiong, 2010). SPI produces flexible and clear films with good oxygen and lipid barrier characteristics. Researchers in Kentucky University investigated that disulphide bonds were the main force to establish the film and low temperature was able to decrease the brittleness (Jiang, Xiong, Newman, & Rentfrow, 2012).

**Milk protein.** Milk proteins can be divided into casein and whey protein. Casein represents 80% of the total milk protein and consists of α, β, and κ-casein. The low cysteine levels in casein result in little disulfide cross-linking with an open random-coil structure, while the high proline content results in better emulsifying properties compared to whey protein (Khwaldia, Perez, Banon, Desobry, & Hardy, 2004). A more detailed discussion of milk proteins follows.

**Egg protein.** The part which can be used as edible films from egg protein is egg albumin. It has water holding ability, foaming capacity, and emulsifying ability. Egg albumin can form thermally induced gels, which makes it a potential edible coating
Its main components, ovalbumin, is believed to be responsible for the gelling properties. A study showed that egg albumin dip produced samples with the highest lipid reductions compared with other groups (Myers & Brannan, 2011). Sathivel explored several materials as chitocan protein coatings of pink salmon. Egg albumin was found to significantly keep moisture content high (Sathivel, 2005).

Whey Protein

**Characteristics of whey protein.** Whey is a by-product of the cheese-making industry. The most important constituent of whey is whey protein (WP) which is generally used in infant formulas and sports food as a nutritional supplement (Jooyandeh, 2011; Ramos, Fernandes, Silva, Pintado, & Malcata, 2012). It is the watery protein of milk remaining after two processes: milk coagulation and removal of the curd. Whey protein consists of a number of individual protein components, such as β-lactoglobulin, α-lactalbumin, bovine serum album, immunoglobulin, and proteose-peptones. The two most abundant proteins are β-lactoglobulin (50-55%) and α-lactalbumin (20-25%) (Krochta & De Mulder-Johnston, 1996).

Whey protein has been used in confectionery, bakery and ice cream products, infant formula, health foods, and sports bars. From the perspective of nutrition, whey protein has many good qualities. There is experimental and clinical evidence that whey protein, as opposed to slowly digested protein such as casein, increases the synthesis of protein in the aged (Rieu et al., 2007). Whey protein may have antioxidant properties owing to the rich concentration of cysteine, which is essential for the production of endogenous glutathione, one of the most important organic scavengers (Middleton, Jelen,
& Bell, 2004). Since leucine-rich whey proteins were efficient in improving muscle protein synthesis, nutritional supplements containing them may be efficient in preventing sarcopenia in the elderly and would represent a safe and optimized nutritional strategy (Rieu et al., 2007). In addition, recent investigations aimed to find new uses of whey protein. Many proteins are insoluble at their isoelectric points (ISP). Whey proteins, however, are soluble at their isoelectric points and can be utilized at these pH values (Picone, Takeuchi, & Cunha, 2011). This makes whey protein concentrates uniquely applicable for addition to acidic food.

Whey protein can be added into food products as an emulsifier. For example, WPI is a good way to use a readily available source, increase the nutritive value of the product and take advantage of a good emulsifier. It has specific conditions at which it can function as an emulsifier. Demetriades showed that when an emulsion gets close to WPI’s isoelectric point (~4.8) it tends to become a viscous paste and syneresis occurs (using 2 wt%); flocculation was seen to occur for pH values 4-6 (Demetriades & McClements, 1998).

As one of the primary proteins in human breast milk, α-la can be applied to improve the overall amino acid composition of an infant formula as research has demonstrated it’s benefit to brain function (Markus, Jonkman, Lammers, Deutz, Messer, & Rigterling, 2005). The first advantage of α-la is that it has lower allergenicity than β-lg, which is not present in human milk (Iametti et al., 2002). Thus, it is an excellent source of whey protein for lactose-free formulas. Another desirable aspect of α-la is its high concentration of one of the limiting amino acids, tryptophan (Messer & Rigtering, 2005).
However, limited with the expense of extraction of α-la, it has not been used widely in food industry.

It is reported that β-lg has emerged in recent years in food industry. Several studies have applied β-lg as an important food additive and a nutriceutical (Zhang et al., 2012). Because this protein can be a good source of essential and branched amino acids (BCAAs) like leucine, isoleucine, and valine. Athletes or body builders use it as a commercial supplement (Pihlanto-Leppala, Antila, Rinta-Koski, & Paakkari, 1997). Some studies indicated that β-lg showed the improvement of the emulsifying and foaming properties. Foam stability was increased by the interfacial and foam properties of hydrolysates of β-lg (Wierenga, & Gruppen, 2010). Like whey protein, β-lg has been used for its gelation. The heat-set gelation of β-lg could aggregate under different conditions to work as a film or coating, which expands its application (Ridout, Mackie, & Wilde, 2004).

However, due to the high price of purification, neither α-la nor β-lg gets the wide application in factorial processing as whey protein nowadays (Iametti et al., 2002; Zhang et al., 2012).

**Whey protein inhibition of oil absorption.** Studies have investigated the effectiveness of whey protein to reduce fat content as an ingredient of coatings. They connected several key points that affect both oil absorption and protein structure, especially in regards to the gel formation.

Gel formation of food proteins has been viewed as a two-stage sequential process involving initial denaturation followed by sequent protein-protein and crosslinking
interactions, resulting in the formation of a three-dimensional gel matrix (Ferry, 1948).

Several factors have been studied as influences on the gelling properties of food proteins. These include their amino acid composition and sequence, their secondary and tertiary conformation in solution as well as their stability to thermal denaturation. However, seven genetic variants of this protein have been identified which differ in their amino acid composition and sequence (Rabiey & Britten, 2009). The different amino acid composition and sequence play an essential role in the flexibility of the gel network.

Proteins are widely used in the food industry as additives to create gel structures. The gel properties of protein gels depend on the structural characteristics of the proteins used (e.g., charge, hydrophobicity). In order to form a gel, the small protein aggregates should cluster together to form larger aggregates that will form a space-filling network upon cooling (Creusot, Wierenga, Laus, Giuseppin, & Gruppen, 2011). As an ideal system, the swelling of the gel is determined by thermodynamic equilibrium, which depends on the pH inside the gel. The pH inside the gel is in turn controlled by the diffusion of alkali inside the gel (in parallel with consumption of hydroxyl ions as they are consumed by ionization). The work on β-lg gels showed that this type of protein gel behaves as an ideal system, as a changeable polyelectrolyte polymer. This approach has been used successfully to model the diffusion of NaOH into the gel. The β-lg gels swell in the absence of salts at neutral pHs in order to reach the thermodynamic equilibrium (Mercadé-Prieto, Paterson, & Wilson, 2008).

Protein gels can be formed by the addition of salts, the action of enzymes, changes in pH or by the application of heat. Whey protein gels are obtained by heating,
therefore, this discussion will be limited to the mechanisms of heat-induced protein gelation. The effects of ionic strength and mono- and divalent cations on the functional properties of whey protein products have been demonstrated in several studies. When used in combination with WPC, CaCl₂ contributes to gel strengthening via enhancing myosin cross-linking and inhibiting proteolysis. Furthermore, cross-linked proteins formed during setting were more likely to be resistant to proteolysis (Benjakul, Phatcharat, Visessanguan, & Yarnpakdee, 2010). Essentially, as pH was increased away from the ISP, the increased ionic strength caused the protein to unfold more extensively and aggregate more rapidly, producing a more elastic and less permeable network. At neutral pH, the increase of NaCl concentration made WPI gels gain a more open and coarse structure and have increased permeability. At high salt concentrations, protein-protein interactions lead to the formation of a network of aggregated particulates while at intermediate salt concentration the gel network consisted of a mixture of particulate and fine-stranded protein aggregates (Abd El-Salam, El-Shibiny, & Salem, 2009). The advent of new applications for whey proteins, such as delivery systems and encapsulation of nutraceuticals, and edible films, requires whey protein products of tailored functional properties (Abd El-Salam et al., 2009).

The protein concentration has an influence on building protein network. According to the evidence from protein studies, with a too low level of concentration, protein interaction appeared to occur more often within a molecule than between molecules (Belitz & Grosch, 1999). This can change the properties of the final protein matrix. Also, the intermolecular crosslink in the matrix was affected. Considering the
conversion, hydrolysis, and disulphide bonds, the subsequent aggregation was established faster when more β-lg became fibrils under higher protein concentration (Bolder, Vasbinder, Sagis, & van der Linden, 2007).

A previous study of Mah et al. (2008) determined the importance of pH on the barrier properties of WPI. Their results indicated that low pH levels reduced fat content in the fried chicken. The authors speculated that the electrostatic repulsion was related to the different types of bonds at different pH levels. That is, the high percentage of noncovalent bonds increased the random aggregation (Mah et al., 2008). Another important speculation in this study was the relationship between the gel structure and ISP of whey protein. At the pH level below the ISP, gels were thought to have large, fibrillar aggregates and large voids. In contrast, the alkaline gels, probably contained much smaller voids, which led the food surface to suck more oil during cooling phase (Dana & Saguy, 2006).

Dragich and Krochta (2010) combined the wheat flour with whey protein applied as a solution coating for fat-uptake reduction fried chicken. The results indicated whey protein was beneficial to the reduction. They thought it might be a result of modification of filling pores in the protein, which decreased both trapped oil and surface area through where the oil diffused (Saguy & Pinthus, 1995). Another possible reason for this reduction came from the oil-holding capacity of whey protein, similar to the water-holding capacity of gums. The additional protein in solution diffused the wheat flour and modified the oil-holding capacity of the entire coating.
The fat-uptake amount is affected by the capillary pressure in the whey protein matrix. Hong and Krochta (2006) investigated the oxygen permeation properties of whey-protein-coated plastic films under different temperature and base film. Their results showed the whey protein films could be a good oxygen barrier under low moisture conditions. Considering the oil absorption mechanism of capillary pressure, which is mentioned before, less oxygen in the crosslink of the coatings could keep the oil absorption of the food.

Heat treatments induce several conformational changes in the structure of whey proteins, which depends on the heating conditions, and these changes are reflected in whey protein functionality. Under moderate heat treatment (60–70 °C), structural unfolding of the proteins occurs, while at higher temperatures protein aggregates (Schmidt, Packard, & Morris, 1984). Heating treatment increased the rheology β-lg emulsifier to aggregate in oil droplet interactions. It yielded a 10-fold stress after being heated in oil in water emulsions (Knudsen, Ogendal, & Skibsted, 2008).

Heat denaturing of whey proteins exposes free sulfhydryl groups which promote intermolecular disulfide bond formation, thus allowing formation of insoluble films. Transparent, flexible, insoluble films can be formed by drying aqueous solutions of heat-denatured WPI and low-molecular-weight plasticizer. Plasticizers are seen as interacting with polymer chains, thus reducing chain-to-chain interaction and decreasing film brittleness (Laleye, Wasesa, & Jobe, 2008).

The whey protein concentrate gels also contain a large amount of protein, particularly β-lg, but do not always behave like the β-lg gels. There are several
differences between the pure β-lg gels and those generated from whey protein products. One thing is the presence of other proteins (e.g., bovine serum albumin, α-lactalbumin) and milk compounds (e.g., lactose). Another important difference is the gel morphology. The β-lg gels were transparent; while the whey protein concentrate materials were opaque and particulate (Stading, Hermansson, & Langton, 1992). This difference decreases the function of β-lg to control the gel formation completely.

**Properties of β-lactoglobulin.** The β-lactoglobulin is the major bovine whey protein and generally accounts for 50% of the total whey protein in ruminants and 10% of the total protein in bovine milk (Creamer et al., 2003). As a soluble and globular protein, β-lg has two main isoforms—genetic variants A and B. As the most abundant protein in whey, β-lg is largely responsible for solubility, gelation, foaming, emulsification, and flavor binding.

Renard and Lefebvre (1992) developed a simple model to take a look at the β-lg heat-induced gelation when pH level and ionic strength changed. Their results mentioned the range of electrostatic interactions in the β-lg heat-induced gel included the free energy of aggregation related to the gelation. Therefore, they reported that at extreme pH values, heat treatment led to more expanded conformation when β-lg was highly ionized than the statement of it in the intermediate range of pH levels.

The β-lg was investigated to form gel under thermal treatment in other experiments. Electrostatic and hydrophobic interactions worked at the same time to affect the gelation. The β-lg was positively charged, as well as underwent electrostatic repulsion at low pH levels. Increasing temperature buried the hydrophobic residues so that protein
became soluble and easily to produce aggregation (Mudgal, Daubert, Clare, & Foegeding, 2011). Their results also showed that the peptin hydrolysis could affect the apparent viscosity of heated β-lg dispersion.

The β-lg is a self-assembly molecule. It aggregated to be fibril gels when heated in an experiment. Researchers studied its rheological characteristics, like reactivity of polymerization sites and charge distribution. But a model was difficult to establish because of the variety of effects in this gel system (Lovedaya, Wanga, Raob, Anemac, & Creamera, 2009).

With the help of high performance liquid chromatography (HPLC), a group of researchers at North Carolina State University found that rate of β-lg aggregation depended on larger critical size needed at lower initial protein concentrations (Mudgal, Daubert, & Foegeding, 2011). Affected by different pH, the gelation of β-lg appeared different. Under lower pH levels, which are near the isoelectric point, the protein formed a soft gel. While at pH away from the isoelectric point, the subject showed little aggregation. This might come from the absence of counter ions (Haque & Sharma, 2002). The changes of the final gels showed the potential property of β-lg to modify whey protein, or a food coating to decrease the oil absorption of the fried food.

**Properties of α-lactalbumin.** In mature bovine milk, α-lactalbumin comprises approximately 3.4% of the total protein or 20% of the whey proteins. The structure of α-la is stabilized by four disulfide bonds and by the binding of calcium to the high-affinity Ca2+ binding site of the protein.
Oil inhibition using WPI was speculated to be controlled by α-la. Rabiey and Britten (2009) observed that α-la worked in gelation of whey protein. Increasing the proportion of α-la in the polymer dispersions resulted in more turbid gels characterized by an open microstructure. At the same time, elastic and viscous moduli were reduced, while the relaxation coefficient and the stress decay rate constants were increased by raising the proportion of α-la in the gel. Increasing the proportion of α-la promoted the formation of smaller protein polymers. A rheological study showed that hydrolysis of isolated α-la and of WPI with highly specific endoproteinases Glu-C, Lys-C, Arg-C and trypsin can be used to improve emulsion activity and stability, as well as foaming capability and stability (Vojdan & Whitaker, 1998). Although not many studies proved that α-la worked successfully as an oil barrier for deep-fried food, the function of α-la in thermal gelation of whey protein creates a way to study the oil absorption of protein-coated films.

Conclusion

The low-fat food needs require the coating to reduce oil absorption of the food products. Adding an additional material is a good way to establish an oil barrier on the surface. Whey protein shows critical properties to be this material. Its gelation and reactions related this under heating treatment have been investigated in many previous studies. The two main components, α-la and β-lg have similar advantages for this function. But there is not much evidence comparing and contrasting these three potential materials.
Chapter 3: Methodology

Materials

All food ingredients were purchased from local food distributors. WPI, α-la, and β-lg were donated from Davisco Foods International (Eden Prairie, MN, U.S.). Sodium bisulfate (pHase) was donated by Jones-Hamilton Co., Walbridge, OH. All other chemicals were purchased from Fisher Scientific (Fair Lawn, NJ).

Fried Breaded Chicken Samples Preparation

For each replication, chicken tenderloins were cut into 10 ± 1 gram pieces. The narrow tips were discarded to make the pieces as uniform as possible. All the pieces were kept into a refrigerator (4 °C) for as long as 12 hours before being coated.

The coating process included four parts: predusting, battering, breading, and dipping, although the controls were not dipped. The predust coating consisted of all-purpose flour. The batter was prepared from 48.75% (w/w) wheat flour, 48.75% corn flour, 1.0% xanthan gum, 1.0% salt, 0.5% baking powder and deionized water (Sahin, Sumnu, & Altunakar, 2005). This batter had been used in previous experiments in our laboratory (Mah et al., 2008). The batter was standardized based on viscosity, using a modified Stein Cup method. The Stein Cup method is a method commonly used in industry whereby viscosity is determined based on the time required for batter to pass through a round-bottom cylindrical cup of known volume with a hole in the bottom (Anderson, Bruno, & Smith, 2011). In this experiment, a 4-in diameter funnel was used in place of the Stein Cup. After the funnel was filled full of batter, the viscosity of the
batter was considered standardized when all the running batter transits the drain hole in 11 seconds.

The breading consisted of Japanese Bread Crumbs which was pass through a 2 mm sieve (Fisherbrand Test Sieve, Fair Lawn, NJ) to assure a particle size of less than 2 mm.

The dips were composed of 10% (w/w) protein, solubilized in deionized water and then adjusted to pH 2 using pHase, a low flavor impact acidulant. The dips were kept refrigerated (4 °C) for up to 12 hours before use. Chicken pieces were dipped in 10% (w/w) WPI, α-la, β-lg, or a combination of α-la and β-lg (25%/75%, 50%/50%, and 75%/25%) at pH 2. This pH showed high lipid reduction in the previous study (Mah et al., 2008). An undipped control and chicken pieces dipped in water at pH 2 (0% protein) were serve as controls. These two control groups were applied to compare the difference between not only the typical industry frying process and experimental frying, but also dipping groups. All groups and their protein contents are shown in Table 2.
Table 2

Experimental Groups and Their Protein Contents

<table>
<thead>
<tr>
<th>Experimental treatments</th>
<th>WPI (%)</th>
<th>β-Lactoglobulin (%)</th>
<th>α-Lactalbumin (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undipped control (not dipped in any solution)</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>100% Water control (dipped in water only)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10% WPI</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10% β-Lg</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (3:1)</td>
<td>0</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:1)</td>
<td>0</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:3)</td>
<td>0</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>10% α-La</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

Note. All the solutions are adjusted to pH 2. None indicates that samples in this group did not get any dip. Therefore, there is nothing in their dips.

In groups of four, chicken pieces were dipped into the predust, batter, breading, and protein dips (if required). Samples were weighed before and after each step. Samples were fried in 180 °C frying oil in a deep fryer (Presto® Dual ProFryTM/1800W, National Presto Industries Inc., WI., U.S.) for 3 minutes till their central temperature reached 77
°C, which is the temperature to decrease the level of harmful microorganism to an acceptable level (Jackson et al., 2009). Fried samples were allowed to drip for a few seconds, then weighed immediately. Samples were analyzed immediately after frying.

The oil applied in this experiment was all-purpose vegetable oil (Crisco, The J.M. Smucker Co., Orrville, OH., U.S.) made of soybean oil. To ensure consistent quality, the use of the frying oil was limited to 5 hours. In addition the order of experimental groups was in random sequence generated by Microsoft Excel (Microsoft Office, Version 14.0 2010, Microsoft Co., Redmond, WA). In each replication, the experimental groups were randomly ordered (see Appendix A).

**Data Collection and Analysis**

**Sample characteristics.** During sample preparation, samples were weighed before and after each coating and frying step. Four chicken pieces were prepared together and weighed together. Since they had similar raw weights, their coating pickups were the divided equally from their total weight. The equations applied to calculate pickup were shown as follows:

\[
\text{% Predust pickup:} \\
\text{Predust pickup (\%) = } \frac{\text{weight before pre dusting (g)}}{\text{weight after pre dusting (g)}} \times 100\% \quad (1)
\]

\[
\text{% Batter pickup:} \\
\text{Batter pickup (\%) = } \frac{\text{weight before batter (g)}}{\text{weight after batter (g)}} \times 100\% \quad (2)
\]

\[
\text{% Breading pickup:} \\
\text{Breading pickup (\%) = } \frac{\text{weight before breading (g)}}{\text{weight after breading (g)}} \times 100\% \quad (3)
\]
% Dip pickup:

\[
\text{Dip pickup} (\%) = \frac{\text{weight before dip (g)}}{\text{weight after dip (g)}} \times 100\%
\]  

Total pickup:

\[
\text{Total pickup} = \text{predust pickup} + \text{batter pickup} + \text{breading pickup} + \text{dip pickup}
\]

% Total pickup:

\[
\text{Total pickup} (\%) = \frac{\text{total pickup (g)}}{\text{raw weight (g)} + \text{total pickup (g)}} \times 100\%
\]

Yield:

\[
\text{Yield} (\%) = \frac{\text{weight after frying (g)}}{\text{weight before frying (g)}} \times 100\%
\]

**Color analysis.** The color of chicken samples were analyzed using a colorimeter (Konica BC-10, Konica Minolta Sensing Americas Inc., Ramsey, NJ). The CIE L*, a*, and b* values were generated. The L* value represents darkness from black (0) to white (100). Positive a* values represent red, and negative a* values represent green. Positive b* represent yellow and negative b* values represent blue. Six pieces from each treatment group were tested for color. In each case, a piece of plastic wrap was put on the samples after 5 minutes after frying and the color was determined.

**Texture analysis.** A Ta-XT2i texture analyzer (Texture Technologies Corp., Scarsdale N.Y., U.S./ Stable Micro Systems, Godalming, Surrey, U.K.) were used to test the texture characteristics of the samples. The samples were placed on the center of a flat platform and a 70 mm knife-blade probe cut through the samples at a crosshead speed of 10 mm/s to a depth of 5 mm. Since the average thickness of the coating system is around
2 to 3 mm, the assay determined attributes about the crust region and the underlying substrate. The texture analyzer was controlled by Texture Expert Software (Texture Technologies Corp.). Four textural attributes as reported in previous research (Brannan, 2008) were generated from the force-deformation curve (see Figure 2). Hardness, measured in grams, is the maximum force required to penetrate the sample 5 mm. Crust fracture force, measured in grams, is the force required to penetrate the crust of the sample. Crust work, the area under the crust fracture peak, is the work required to break the crust. Total work, the area under the hardness peak and the crust fracture peak, is the total work required to penetrate the sample by 5 mm. Six pieces from each treatment were analyzed.

**Moisture content.** Moisture analysis was conducted after color and texture analysis. Moisture content was tested via oven drying. Six samples from each treatment were randomly collected. From each of the six samples, two moisture measurements were obtained in order to increase the consistency of the result. Samples were ground until homogenous, then 1 g of sample was placed on a piece of weighed and labeled filter paper. Samples were dried oven at 80 °C for up to 24 hours. After being cooled down in
an incubator, the dry sample and the filter paper were weighed. The moisture content was calculated in Equation 6:

$$\text{moisture content (\%) = \frac{\text{dry sample weight (g)} - \text{initial sample weight (g)}}{\text{initial sample weight (g)}} \times 100\%} \quad (6)$$

**Lipid analysis.** Lipid analysis was performed after moisture content analysis via the Soxhlet extraction process (the Association of Analytical Communities [AOAC], 2000). The principle is based on the solubility of lipid in solvent. In this experiment, it was hexane. The dry sample and its filter paper from moisture analysis were placed into a system where pure hexane could come in contact with the sample. After 24 hours of extraction, they were dried again. The final weight was the weight of sample without moisture and lipid. The lipid content was calculated in Equation 7:

$$\text{lipid content (\%) = \frac{\text{dry sample weight (g)} - \text{final sample weight (g)}}{\text{initial sample weight (g)}} \times 100\%} \quad (7)$$

**Experimental Design and Statistical Analysis**

Four complete replications were performed for the study. Statistical analysis was operated via the Statistical Package for the Social Sciences program (PASW Statistics, version 18.0.0 2009, SPSS Inc., Chicago, IL). Variances analysis for each of the eight treatments (see Table 3) was conducted via ANOVA (Analysis of Variance) to analyze differences between all the treatments. Significant differences were determined at the confidence level of $p < 0.05$. Post hoc means separation was determined via using Duncan’s Multiple Range test.
Chapter 4: Results

Controls

In this study, three of the eight treatments served as control groups. One treatment was not dipped after batter and breading was applied. This treatment, which reflects the current standard industry practice, served as the true control for the study and is the benchmark to which all other treatment means are compared. Hereafter it may be referred to as the undipped control. A group was treated by a post-breading application of a water only dip, i.e. 0% protein. This group hereafter may be referred to as the negative control. Another group was treated with a post-breading dip of 10% WPI solution which has been shown in previous studies to reduce oil absorption during frying of breaded chicken (Mah, Price, & Brannan, 2008; Dragich & Krochta, 2010). This treatment served as the positive control and hereafter may be referred to as such.

Replications

The complete study was replicated four times. When the main effects of lipid and moisture content were considered, i.e. pooled across all other treatment variables, significant differences were observed for both lipid and moisture content of boneless deep fried chicken pieces (see Figure 3). The highest lipid content (7.7%) appeared in the first replication. It is significantly higher than the other replications at p<0.001. Moisture content also was significantly different across replications. However, when the first replication (the one that exhibited a difference in lipid content) was removed from the analysis, differences still existed in moisture content, and there were several significant differences for coating pickup, yield, coating color, and texture (data not shown). In fact,
differences were observed regardless of which replication was not included in the ANOVA. Therefore, it is important to account for the variance due to replication in the analysis by including replication as a main effect in the analysis. Also, there appears to be no systematic reason to exclude any of the replications from the analysis. A similar phenomenon involving differences among replications was observed in earlier work utilizing egg protein as an oil inhibitor (Myers, 2011), and a similar decision to include all replications was reached.

Figure 3. Effect of replication on lipid and moisture content of boneless deep-fried chicken pieces. Different letters in moisture content indicate a significant difference at p < 0.05. Different letters in lipid content indicate a significant difference at p < 0.05.
**Coating Pickup**

Coating pickup for boneless deep fried chicken pieces is shown in Table 3. There were no significant differences in raw weight, predust pickup, and batter pickup. However, samples treated with 10% protein with β-lg:α-la (3:1) exhibited the lowest batter pickup (2.7g). WPI-treated samples had the highest batter pickup (3.6g) and breading pickup. They were coated the most Japanese breadcrumb, which was significantly more than the undipped control and 10% protein composed of β-lg:α-la (1:1) treatment. All of the treatment groups were coated with additional protein dips with the exception of the undipped control. None of the dipped treatments exhibited a dip pickup that was significantly different than either the negative (100% water dip) or positive (WPI) control. Since the undipped control did not receive a postbreading dip, it was significantly lower in total pickup than all of the other treatment groups. However, there were no significant differences between the dipped samples in total coating weight, compared to the 100% water treatment.

Breaded foods are classified by the U.S. Department of Agriculture (USDA, 2001b) into categories based on total batter/breading pickup. USDA Commercial Item Description A-A-20276A (USDA, 2001a) authorizes the use of certain batter/breading combinations. According to section 5.1.8, the samples produced in this study cannot be classified as nuggets, fingers, strips, or patties, but rather as fritters because the combined batter and breading exceeds 30% by weight.
Table 3

*Mean Values for Raw Weight, Predust Pickup, Batter Pickup, Breading Pickup, Dip Pickup, Total Pickup, and Yield for Deep-Fried Chicken*

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Raw weight (g)</th>
<th>Predust pickup (g)</th>
<th>Batter pickup (g)</th>
<th>Breading pickup (g)</th>
<th>Dip pickup (g)</th>
<th>Total pickup (g) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undipped control</td>
<td>10.5</td>
<td>0.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>3.2&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>None</td>
<td>5.0&lt;sup&gt;d&lt;/sup&gt; 32.3</td>
</tr>
<tr>
<td>100% Water control</td>
<td>10.7</td>
<td>0.5&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>3.1&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.7&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.3&lt;sup&gt;a,b,c&lt;/sup&gt; 40.6</td>
</tr>
<tr>
<td>10% WPI</td>
<td>10.5</td>
<td>0.7&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>3.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.1&lt;sup&gt;a&lt;/sup&gt; 43.5</td>
</tr>
<tr>
<td>10% β-Lg</td>
<td>10.7</td>
<td>0.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.2&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.9&lt;sup&gt;c&lt;/sup&gt; 39.2</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (3:1)</td>
<td>10.8</td>
<td>1.0&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>2.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.4&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.8&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>6.9&lt;sup&gt;c&lt;/sup&gt; 39.0</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:1)</td>
<td>10.5</td>
<td>0.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>3.4&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.8&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>7.1&lt;sup&gt;b,c&lt;/sup&gt; 40.3</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:3)</td>
<td>10.4</td>
<td>1.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>2.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.7&lt;sup&gt;a,b&lt;/sup&gt; 42.5</td>
</tr>
<tr>
<td>10% α-La</td>
<td>10.7</td>
<td>0.5&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>3.1&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.8&lt;sup&gt;c&lt;/sup&gt; 38.9</td>
</tr>
</tbody>
</table>

*Note.* Undipped control serves as the control for prefrying treatment. Different letters within a column indicate a significant difference at p<0.05. None indicates that there was no dipping step.

Cooking yield is shown in Table 4. The prefrying weight of the undipped control (15.5g) was significantly lower than all of the other treatments due to the fact that it did not receive a postbreading dip. There were no differences in prefrying weight for any of the treatments compared to the negative (100% water) and positive (WPI) controls. When
comparing the postfrying weight, there were no significant differences between the
undipped control and all the dipped treatments. This implies that the undipped control
had a much higher cooking yield than the dipped treatments. This is due to the fact that
the undipped samples lost less weight during frying than the dipped treatment groups.
However, there were no significant differences in weight lost during frying between any
of the treatments compared to the negative (100% water) and positive (WPI) controls.

Table 4
Weights for Prefrying Piece, Postfrying Piece and Their Difference (Mean Values) for
Deep-Fried Chicken

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Prefrying weight (g)</th>
<th>Postfrying weight (g)</th>
<th>Weight difference (g)</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undipped control</td>
<td>15.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>-2.5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>87.7</td>
</tr>
<tr>
<td>100% Water control</td>
<td>18.0&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>13.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>-4.4&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
<td>75.6</td>
</tr>
<tr>
<td>10% WPI</td>
<td>18.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-4.4&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
<td>75.8</td>
</tr>
<tr>
<td>10% β-lg</td>
<td>17.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-3.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>79.5</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (3:1)</td>
<td>17.7&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>13.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-4.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>74.0</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:1)</td>
<td>17.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.5&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>-4.1&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>76.7</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:3)</td>
<td>18.1&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>13.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-5.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.4</td>
</tr>
<tr>
<td>10% α-la</td>
<td>17.5&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>13.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-4.5&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
<td>75.4</td>
</tr>
</tbody>
</table>

*Note.* Undipped control serves as the control for prefrying treatment. Different letters
within a column indicate a significant difference at p < 0.05. None indicates that there
was no dipping step.
Effects of Prefrying Treatments on Lipid and Moisture Content

The existence and type of dip affected the final lipid content. The results are shown in Table 5. As expected, the lipid content of the negative control samples (100% water dip) was not significantly different from that of the undipped control, and the WPI-dipped positive control samples exhibited a significant 18% reduction in lipid compared to the undipped control. Two other treatment groups exhibited significantly lower lipid content compared to the undipped control group. Samples dipped in 10% β-lg exhibited a 19.5% reduction in lipid, and the protein treatment composed of β-lg:α-la ratio of 3:1 produced a 15.6% reduction. Three treatment groups, composed of β-lg:α-la ratios of 1:1, 1:3 and 10% α-la protein did not produce samples with significantly lower lipid compared to the undipped control.

The results of the dip effect on moisture content for deep fried chicken pieces are shown in Table 6. These treatments significantly affected the moisture content of chicken pieces. Compared with all of the other groups, the undipped control had significantly lower moisture content (51.2%). There are some differences between different types of dip. There were differences in moisture content between six protein groups. The mixture treatments, 10% protein composed of β-lg:α-la (3:1), β-lg:α-la (1:1), and β-lg:α-la (1:3) had similar moisture contents. The only significant differences existed in protein groups showed between 10% protein composed of β-lg:α-la (3:1) dip and 10% β-lg dip.
Table 5

Means and Standard Deviations (SD) for The Dip Effect of Lipid Content (%) and Moisture Content (%) for Deep-Fried Chicken

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Lipid content</th>
<th>Moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (%)</td>
<td>± SD (%)</td>
</tr>
<tr>
<td>Undipped control</td>
<td>7.7&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.6</td>
</tr>
<tr>
<td>100% Water control</td>
<td>8.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.6</td>
</tr>
<tr>
<td>10% WPI</td>
<td>6.3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.4</td>
</tr>
<tr>
<td>10% β-Lg</td>
<td>6.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.5</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (3:1)</td>
<td>7.5&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>1.5</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:1)</td>
<td>6.5&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>1.4</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:3)</td>
<td>7.2&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
<td>1.7</td>
</tr>
<tr>
<td>10% α-La</td>
<td>6.9&lt;sup&gt;b,c,d&lt;/sup&gt;</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Note. Undipped control serves as the control for prefrying treatment. Oil reduction is the difference oil content from the control group. None means no oil reduction because this group is the control. Different letters within a column indicate a significant difference at p < 0.05. Lipid reduction is the percentage of the lipid content difference (between the current group and the undipped control) in the lipid content of the undipped control. None means there is no lipid content difference compared this group itself.
Effects of Prefrying Treatments on Coating Color

The results of color values for deep fried chicken pieces were shown in Table 7. The L* values ranged from 51.0 to 55.3 for all the treatments. None of the treatments differed from the undipped or negative controls with the exception of the 10% β-lg group, which was slightly but significantly lighter than the undipped control. No significant differences were observed for any of the treatments compared to the undipped or negative controls. All the a* values were positive, indicating that the color of the cooked coating were reddish. All the b* values were positive, indicating a yellowish color of the cooked breading. No differences were observed between the undipped, negative, or positive control samples. None of the protein-dipped samples were significantly different from each other, although the 10% protein dip of pure β-lg and β-lg:α-la ratio of 1:3 and 3:1 produced samples that were significantly more yellow than either the undipped or negative controls.
Table 6

Means and Standard Deviations (SD) for The Main Effects of Surface Color Values for Deep-Fried Chicken

<table>
<thead>
<tr>
<th>Treatments</th>
<th>a* ± SD</th>
<th>b* ± SD</th>
<th>L* ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undipped control</td>
<td>+13.9&lt;sup&gt;a,b&lt;/sup&gt; ± 1.9</td>
<td>+20.0&lt;sup&gt;c&lt;/sup&gt; ± 3.3</td>
<td>52.6&lt;sup&gt;b,c&lt;/sup&gt; ± 3.5</td>
</tr>
<tr>
<td>100% Water control</td>
<td>+13.3&lt;sup&gt;a,b&lt;/sup&gt; ± 2.5</td>
<td>+21.0&lt;sup&gt;b,c&lt;/sup&gt; ± 4.0</td>
<td>53.6&lt;sup&gt;a,b,c&lt;/sup&gt; ± 4.0</td>
</tr>
<tr>
<td>10% WPI</td>
<td>+14.3&lt;sup&gt;a&lt;/sup&gt; ± 2.9</td>
<td>+21.2&lt;sup&gt;a,b,c&lt;/sup&gt; ± 4.8</td>
<td>51.0&lt;sup&gt;c&lt;/sup&gt; ± 5.7</td>
</tr>
<tr>
<td>10% β-Lg</td>
<td>+13.1&lt;sup&gt;a,b&lt;/sup&gt; ± 3.1</td>
<td>+23.7&lt;sup&gt;a&lt;/sup&gt; ± 6.0</td>
<td>55.3&lt;sup&gt;a&lt;/sup&gt; ± 5.2</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (3:1)</td>
<td>+12.7&lt;sup&gt;b&lt;/sup&gt; ± 1.9</td>
<td>+23.2&lt;sup&gt;a,b&lt;/sup&gt; ± 3.3</td>
<td>55.2&lt;sup&gt;a,b&lt;/sup&gt; ± 5.6</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:1)</td>
<td>+13.0&lt;sup&gt;a,b&lt;/sup&gt; ± 2.2</td>
<td>+21.9&lt;sup&gt;a,b,c&lt;/sup&gt; ± 4.2</td>
<td>53.9&lt;sup&gt;a,b&lt;/sup&gt; ± 4.1</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:3)</td>
<td>+13.6&lt;sup&gt;a,b&lt;/sup&gt; ± 2.1</td>
<td>+23.7&lt;sup&gt;a&lt;/sup&gt; ± 3.7</td>
<td>53.5&lt;sup&gt;a,b,c&lt;/sup&gt; ± 4.4</td>
</tr>
<tr>
<td>10% α-La</td>
<td>+13.1&lt;sup&gt;a,b&lt;/sup&gt; ± 2.6</td>
<td>+21.5&lt;sup&gt;a,b,c&lt;/sup&gt; ± 4.9</td>
<td>53.5&lt;sup&gt;a,b,c&lt;/sup&gt; ± 3.8</td>
</tr>
</tbody>
</table>

Note. Undipped control serves as the control for prefrying treatment. Different letters within a column indicate a significant difference at p < 0.05.

Effects of Prefrying Treatments on Texture Attributes

The results of the texture analysis are shown in Table 8. There are four attributes, hardness, crust fracture, crust work, and total work. Significant differences were seen in all attributes except the ratio of hardness to crust fracture force. No differences between
the undipped and negative (100% water) controls were observed for any of the texture attributes.

Hardness is the force required to penetrate a sample 5 mm through crust (Brannan, 2008). The 10% β-lg group was the only treatment that produced significantly harder samples than the both the undipped, negative (100% water), and positive (WPI) controls. Crust fracture force measures the force required to penetrate the crust region of the patties. It was observed that the WPI dip, the 10% β-lg dip, 10% protein composed of β-lg:α-la (1:3) dip, and 10% protein composed of β-lg:α-la (1:1) dip needed significantly more force to break their crusts compared to the undipped control, although not compared to the negative (100% water) control. Work is a physical measurement that describes the product of a force and the distance through which it acts in the direction of the force. Both work measurements (crust fracture work and total work) exhibited very similar results to those for hardness, as the 10% β-lg group was the only treatment that produced significantly harder samples than the both the undipped and negative (100% water) controls. It appears that the undipped and negative (100% water) controls almost always were the softest and most fragile group with respect to their texture attributes, whereas the 10% β-lg dip was significantly more rigid and stout than these controls.
Table 7
Means and Standard Deviations (SD) for The Main Effects of Texture Attributes of Deep-Fried Chicken

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Hardness ± SD (g)</th>
<th>Crust fracture force ± SD (g)</th>
<th>Ratio ± SD</th>
<th>Crust work ± SD (g.sec)</th>
<th>Total work ± SD (g.sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undipped control</td>
<td>699&lt;sup&gt;c&lt;/sup&gt; ± 323</td>
<td>312&lt;sup&gt;c&lt;/sup&gt; ± 146</td>
<td>2.4 ± 1.0</td>
<td>279&lt;sup&gt;c&lt;/sup&gt; ± 400</td>
<td>409&lt;sup&gt;c&lt;/sup&gt; ± 326</td>
</tr>
<tr>
<td>100% Water control</td>
<td>726&lt;sup&gt;b,c&lt;/sup&gt; ± 327</td>
<td>400&lt;sup&gt;a,b,c&lt;/sup&gt; ± 275</td>
<td>2.4 ± 1.3</td>
<td>325&lt;sup&gt;b,c&lt;/sup&gt; ± 481</td>
<td>456&lt;sup&gt;b,c&lt;/sup&gt; ± 257</td>
</tr>
<tr>
<td>10% WPI</td>
<td>810&lt;sup&gt;b,c&lt;/sup&gt; ± 379</td>
<td>482&lt;sup&gt;a,b&lt;/sup&gt; ± 305</td>
<td>2.3 ± 1.9</td>
<td>346&lt;sup&gt;b,c&lt;/sup&gt; ± 496</td>
<td>548&lt;sup&gt;a,b&lt;/sup&gt; ± 354</td>
</tr>
<tr>
<td>10% β-Lg</td>
<td>992&lt;sup&gt;a&lt;/sup&gt; ± 504</td>
<td>489&lt;sup&gt;a&lt;/sup&gt; ± 398</td>
<td>2.6 ± 1.4</td>
<td>470&lt;sup&gt;a&lt;/sup&gt; ± 715</td>
<td>658&lt;sup&gt;a&lt;/sup&gt; ± 549</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (3:1)</td>
<td>875&lt;sup&gt;a,b&lt;/sup&gt; ± 627</td>
<td>460&lt;sup&gt;a,b&lt;/sup&gt; ± 357</td>
<td>2.2 ± 1.1</td>
<td>409&lt;sup&gt;a,b&lt;/sup&gt; ± 620</td>
<td>476&lt;sup&gt;b,c&lt;/sup&gt; ± 329</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:1)</td>
<td>802&lt;sup&gt;b,c&lt;/sup&gt; ± 355</td>
<td>431&lt;sup&gt;a,b&lt;/sup&gt; ± 230</td>
<td>2.2 ± 1.3</td>
<td>372&lt;sup&gt;a,b,c&lt;/sup&gt; ± 510</td>
<td>522&lt;sup&gt;b,c&lt;/sup&gt; ± 320</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:3)</td>
<td>729&lt;sup&gt;b,c&lt;/sup&gt; ± 354</td>
<td>382&lt;sup&gt;a,b,c&lt;/sup&gt; ± 207</td>
<td>2.3 ± 1.5</td>
<td>338&lt;sup&gt;b,c&lt;/sup&gt; ± 489</td>
<td>400&lt;sup&gt;c&lt;/sup&gt; ± 280</td>
</tr>
<tr>
<td>10% α-La</td>
<td>731&lt;sup&gt;b,c&lt;/sup&gt; ± 405</td>
<td>363&lt;sup&gt;b,c&lt;/sup&gt; ± 247</td>
<td>2.2 ± 0.8</td>
<td>346&lt;sup&gt;b,c&lt;/sup&gt; ± 527</td>
<td>426&lt;sup&gt;b,c&lt;/sup&gt; ± 321</td>
</tr>
</tbody>
</table>

Note. Undipped control serves as the control for prefrying treatment. Ratio indicates the ratio value of hardness to crust fracture force. Different letters within a column indicate a significant difference at p < 0.05.
Chapter 5: Discussion and Conclusion

As mentioned in chapter 2, several mechanisms are theorized to explain how oil can enter a fried food (Saguy & Dana, 2003; Ziaiifar, Achir, Courtois, Trezzani, & Trystram, 2008). The surfactant theory suggests that the dynamic nature of the oil itself may play a role in oil absorption. During frying, polar surface-active agents produced from triglyceride breakdown enhance the contact between the food and the frying oil. These surface-active compounds (diglycerides, monoglycerides, free fatty acids, and glycerol) serve to lower the interfacial tension between the oil and the water (Dana & Saguy, 2006), which increases oil absorption. The effect of oil absorption in the current study caused by the surfactant theory may be minimal because the previous research has shown that oil used over the timeframe employed in this thesis work did not accumulate significant polar compounds (Mah et al., 2008).

Vitrac et al. (2002) describes the water replacement mechanism, characterized by frying oil that is absorbed into the holes and voids in the substrate that are created by water in the substrate as it vaporizes during frying. In the current study, there did not appear to be a direct relationship between moisture loss and oil absorption, which would be expected by this mechanism. This could be partially explained by the fact that moisture loss has been shown to be continuous during frying but oil uptake reaches a maximum level and remains constant until removal of the fried food from the frying medium (Yamsaengsung & Moreira, 2002).
The cooling phase mechanism explains oil absorption after the product is removed from contact with the oil. As water vapor in the substrate condenses, internal pressure is created in the voids no longer being used by steam escaping the product. Oil on the surface of the food is sucked into these voids. Pressure differences have been shown to exist between the surface and the interior of the food as it fries, resulting in a capillary force that drives fluid oil into the food (Ziaiifar et al., 2008).

Based on a previous study, the conditions used in this study, i.e., 10% protein at pH 2, were theorized to promote the creation of a condition through which moisture release and subsequent oil absorption is reduced via the formation of thermally-induced gels (Mah et al., 2008). At low protein levels, thermal gelation produces protein–protein interactions within molecules rather than between molecules (Belitz & Grosch, 1999). At higher protein content, intermolecular crosslinks increase and gelation is more likely to occur. Protein dips at higher pH were shown to have excellent oil inhibition properties, but were unacceptable from a sensory standpoint. Protein dips at lower pH are theorized to produce gels with smaller pores. While increased protein concentration does promote random aggregation due to the close contact between monomers, conditions must be created so that gel formation is not inhibited due to same-charge electrostatic repulsion, i.e., manipulation of pH.

**Effect of Dip Type on Lipid Content and Moisture Content**

The 10% WPI treatment produced an oil reduction of 18% in this study, confirming the oil inhibiting effect of WPI in deep fried ground chicken patties (Mah et al., 2008) and chicken breast strips (Dragich & Krochta, 2010). Mah et al. (2008)
hypothesized that the oil-inhibiting properties of the postbreading dip were due to the role that protein concentration and ionic strength played in WPI gelation. A two-stage sequential process is involved in whey protein gel formation. Initial protein denaturation is followed by protein-protein and crosslinking interactions (Ferry, 1948). As the protein content increased, the intermolecular crosslinks are likely to increase and benefit the gelation process. When the changed molecules are created in a protein solution, they could either enhance or decrease electrostatic repulsion between protein monomers.

Research has shown that when whey protein gels are obtained by heating, the effects of mono- and divalent cations and ionic strength affect the functional properties of whey protein products, such as inhibiting proteolysis and expressible moisture modification (Benjakul et al., 2010).

The current study provides strong evidence that the oil-inhibiting effect of WPI is caused by β-lg and not α-la. The analysis of the effect of dip type on lipid content showed the samples treated with 10% β-lg significantly reduced oil inhibition compared to the controls and that the magnitude of inhibition was not significantly different than that for WPI (see Table 5). The fact that a nonsignificant oil inhibition was observed in samples treated with α-la strengthens this argument.

Differences exist between β-lg and α-la that when taken in the context of oil absorption can be illustrative. The α-la contains four disulfide bridges but no free cysteine (Relkin, 1996), which affects the rigidity of α-la gels. Loveday et al. (2009) reviewed several reports about the rheological characteristics of fibril gels of β-lg and α-la. They found that both β-lg and α-la have been used to create fibrils, which in turn to
create gels. The gel could hold certain amount of oil. However, Bolder, Linden, Sagis, and Hendrickx (2006) observed that no fibril formed on heating pure α-la at pH 2, while fibrils did form in pure β-lg and WPI in this condition. Akkermans (2008) indicated that specific peptides were present in the β-lg fibrils due to the low charge and charge distribution along the sequence. In contrast, the mechanism of α-la fibril formation was speculated to be the outcome of the process depending on the initial concentration of α-la and the presence of calcium (Ipsen & Otte, 2007). It is reasonable that as a consequence of the intermolecular bonds in strand formation, the individually tubular strands had a high stiffness in α-la gels. Otte, Qvist, Skriver, and Ju (1996) discovered that the α-la gels had more than 20 times stiffness than that of equivalent β-lg.

Thus, the reason that the pure β-lg treatment caused a reduction in lipid compared with the controls could be due to the conversion of monomers of β-lg to fibrils and their subsequent aggregation, as speculated by Mah et al. (2008), which may have improved the final gel properties. Dragitch and Krochta (2010) offered several reasons for WPI-induced inhibition of oil absorption. In their study, they speculated that the surface structure of the product may have been modified by the WPI solution by filling pores, which may have reduced the surface area through which the oil is diffused. They also speculated that the interfacial tension between the chicken and oil may have increased by the whey protein. The third explanation pertains to modification of the oil-holding capacity of the whole coating (Dragich & Krochta, 2010).

Mudgal, Daubert, Clare, and Foegeding (2011) observed that heat treatment during normal purification of β-lg was enough to increase the amount of isopeptide
bonding. For example, disulfide bonds are typical isopeptide bonds existing between amino acids. These isopeptide bonds are beneficial to form dimers and oligomers, which improve β-lg aggregation (Nacka, Chobert, Burova, Léonil, & Haertlé, 1998). In the context of the current study, this could mean that processing of β-lg could enhance its oil-inhibiting properties. Mudgal et al. (2011) also speculated that at low pH, conformational changes bury hydrophobic residues in β-lg during heating, increasing their accessibility for aggregation.

The 10% protein treatment composed of β-lg:α-la ratio to 1:1 also significantly reduced lipid levels in the samples, although the results of the other dips composed of mixtures of β-lg and α-la, which did not produce significantly lower lipid levels compared to the control, makes interpretations difficult. As mentioned in chapter 2, there is a case reported that increasing the proportion of α-la could lead to an open microstructure of gels, which then promoted the formation of smaller protein polymers (Rabiey & Britten, 2009). These smaller polymers produced from α-la increased both trapped oil and the surface area where the oil diffused (Saguy & Pinthus, 1995).

Taken together, the fact that processing may enhance the oil inhibiting properties of β-lg and a theoretical basis for oil inhibition by α-la may exist shows the complexity of the dynamics of oil inhibition in the current system. It is likely that β-lg is the dominant protein involved in oil inhibition, but that α-la may have a small role.

The results of the moisture content support this conclusion. Every prefrying treatment except for the negative control (no protein in dip) significantly increased the moisture content of the deep fried breaded chicken pieces. Because all of the substrates
and coatings were the same, this suggests that some barrier properties are causing moisture to be retained in the sample. With respect to the dip type, the moisture content was not very different between each group. Because the water escaping is related to the capillary holes and voids formed in the gels, the same interactions dominate the structure to control the final moisture content.

**Relationship Between the Lipid Content and Moisture Content**

This section will focus on the treatments that caused a significant reduction in oil content compared to the undipped control, especially the 10% WPI and 10% β-lg. An analysis of the results from both lipid content and moisture content showed that all the treatments which showed significantly lower oil content compared to the undipped control contained significantly more moisture. This means the protein dips reduced the oil sucked from the outside and decreased the water escaping from the inside at the same time. This is probably due to the effect of the gel structure on the oil absorption mechanisms.

As a positive control, the 10% WPI treatment once again showed good quality as an oil barrier. This result conformed several conclusions from previous research (Mah et al., 2008; Dragich & Krochta, 2010), although different protein interactions may have been at work in the current system. The theories proposed for WPI-induced oil inhibition during frying in these studies are shown in Table 8.
Table 8

*Proposed Oil Absorption Mechanisms Shown In Similar Studies*

<table>
<thead>
<tr>
<th>Proposed mechanism</th>
<th>Citation</th>
<th>Comparison to our work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam escaping during the frying process formed large voids with low positive vapor pressure to suck more oil in acidic gels</td>
<td>Mah et al., 2008</td>
<td>Similar acidic gel might result in large voids in crust to suck more oil</td>
</tr>
<tr>
<td>Smaller pores formed by the alkaline gels may encourage uptake of oil during cooling</td>
<td>Mah et al., 2008</td>
<td>Similar pH created large pores to reduce oil uptake during cooling phase</td>
</tr>
<tr>
<td>Filling pores reduced both trapped oil and surface area</td>
<td>Dragich &amp; Krochta, 2010</td>
<td>No evidence showed pores were filled</td>
</tr>
<tr>
<td>Interfacial tension increased between chicken and frying oil to reduce fat uptake</td>
<td>Dragich &amp; Krochta, 2010</td>
<td>The polar surface-active agents produced from triglyceride breakdown lowered the interfacial tension to increase oil absorption</td>
</tr>
<tr>
<td>Whey protein became a modification of oil-holding capacity of the entire coating</td>
<td>Dragich &amp; Krochta, 2010</td>
<td>Similar modification was found in the whey protein crust</td>
</tr>
<tr>
<td>Denatured whey protein is relevant to fat-uptake reduction</td>
<td>Dragich &amp; Krochta, 2010</td>
<td>The denatured whey protein isolate played a role in oil adsorption reduction</td>
</tr>
</tbody>
</table>
In Mah et al.’s (2008) research, the investigators hypothesized that steam escaping during the frying process formed large voids with low positive vapor pressure to suck more oil in acidic gels, which can be considered as an effect of water-replacement mechanism. Since the same acidic gel (10% WPI at pH 2) was used in our study, the larger voids were probably worked in the crust to absorb more oil. Another mechanism mentioned by Mah et al. is the cooling-phase mechanism. In their discussion, the smaller pores formed by the alkaline gels may encourage uptake of oil during cooling. The acidic gels in our experiment may have created large pores to release more oil at this moment. Compared to β-lg, α-la is a smaller globular protein with a lower isoelectric point and four disulphide bridges but no free cysteine (Relkin, 1996). It is reported that the gels made from α-la appeared translucent, suggesting a more fine-stranded structure than in gels made from β-lg (Ipsen, Qvist, & Otte, 2001). During the cooling phase, the stability of hydrophobic bonds and salt-bridges in proteins of α-la likely are weaker than that of β-lg. This may result in a more brittle structure. What’s more, since α-la is known to have a primary Ca$^{2+}$ binding site, the salt-bridges with Ca$^{2+}$ were able to change the gel structure through electrostatic interactions during cooling phase.

There were four mechanisms in Dragich and Krochta’s (2010) study. Although they thought about the water escape theory, their main point concerned the filling of pores which they proposed reduced both trapped oil and surface area. There was no relevant evidence in our research that showed the whey protein filled the pores and affected the surface area. The second mechanism is related to the interfacial tension. They speculated that a potential increase in interfacial tension between the coated chicken
and the frying oil contributed to reduced fat uptake. These forces may be counterbalanced by the fact that polar surface-active agents produced from triglyceride breakdown can lower the interfacial tension leading to increased oil absorption. Then they mentioned oil-holding capacity. The modification of the WPI in oil-holding capacity could influence the whole coating. It was speculated the same function in the current study. The WPI built a good film. Thus, the water vapor condensation is decreased. Less oil is sucked from the food surface. Another possible reason comes from the establishment of the fibril gel.

Taking a panoramic view of the situation, the relationship between the lipid content and the moisture content affected by the protein dips is not simple. The protein treatments that decreased lipid content also increased moisture content, but not to the same degree. Other treatments caused the significant retention of moisture in the samples, but failed to create significant lipid reduction. The rheological properties of their fibril gels were sensitive to pH, ionic strength, and thermal history. All the solutions were adjusted to pH 2 in this experiment, which created a low pH environment. This environment has an influence on the polymole charge, hydrophobicity, and electrostatic repulsion of the gel matrix. As a result of the different gelation mechanisms of β-lg and α-la, the β-lg fibril would be more highly charged at low pH within a short time (Akkermans, 2008). By contrast, α-la needed more time to build gels. This time difference plays a role in gel building for the whole protein dip. What's more, since the gel is a complex system, a lot of other factors are likely to affect the final structure. So the functions of β-lg and α-la in gel formation are difficult to be explained simply. Therefore, many factors make this system very difficult to interpret.
Effects of Dip Type on Coating Pickups and Yield

Coating pickup influences the whole weight of the final products. It can affect mouth feeling, flavor, and shelf life. The samples in this study can be classified as fritters because more than 30 percent of the final weight was from coating (USDA, 2001). In its description, the chicken fritters can contain as much as 65% batter and breading, but the meat must be not less than 35%.

There were no significant differences in the individual pickup compared to the undipped control except that the 10% WPI samples received more breadcrumbs. The undipped control group was lighter than others because it was not dipped in the protein solution. That means the protein dipped chicken pieces may have thicker crusts than the traditionally prepared ones.

Food companies must pay attention on their production yield. In our results, the undipped samples had the highest frying yield. The five β-lg and/or α-la treatments did not show significantly different yields from either the negative (100% water) or positive (WPI) controls. The similar applications of β-lg and α-la as whey protein in gelation, foams, emulsions, and films can explain this (Nicolai, Britten, & Schmitt, 2011). However, the 10% β-lg treatment lost the least weight during frying among the dipped treatments. This might be the result of the higher ISP of β-lg improving the thermal gelation, especially in pH 2 solution (Cavallieri & Cunha, 2008).

Effect of Dip Type on Coating Color

The appearance of deep fried chicken has great marketing value. Although the purpose of this study was to investigate the effects of β-lg and α-la in reducing oil, the
change of surface color is an important contributor to the quality of the final product. There were not many significant differences in the results of the coating color of the deep fried chicken pieces. The 10% β-lg treatment produced a lighter and yellowish coating. The 10% protein dips of β-lg:α-la ratio of 1:3 and 3:1 also changed the coatings to be more yellow.

Not many studies focused on the coating color of pure β-lg and α-la. But some previous research accessed the coating color of whey protein in different conditions. Mah and Brannan (2009) conducted a test regarding some sensory properties of deep-fried breaded chicken patties. Compared to their results, the control group in our research was lighter. Their 100% water and 10% WPI dips generated more brown coatings than the similar treatments in this experiment, although this may be due to the fact the samples were made of ground chicken breasts, rather than whole chicken breast as employed in the current study. If this difference produced longer frying times, differences in color could be expected due to the fact that the longer proteins on surface interact with frying oil, the more likely changes to the appearance may be seen.

Effect of Dip Type on Texture Attributes

With respect to the dip type on the texture attributes, significant differences were observed in all of samples (see Table 8). Hardness, crust fracture, crust work, and total work are instrumental texture profile attributes applied to the samples during compression, which are used to mimic the human bite (Brannan, 2007; Meullenet, Lyon, Carpenter, & Lyon, 1998). Although the negative control did not show differences from the undipped control, all the protein treatments exhibited higher values in almost all of
these attributes. The 10% β-lg and β-lg:α-la (3:1) dips produced chicken with higher hardness. The 10% WPI, β-lg, β-lg:α-la (3:1), and β-lg:α-la (1:1) treatments increased crust fracture of their objects. But no significant difference appeared in the ratios of the hardness and crust fracture. The crust work values showed the same result as the hardness ones. In the total work, 10% WPI and β-lg were higher than the control group.

In our results, all the attributes of 10% protein of β-lg were highest and also significantly higher than that of the undipped control. But this group was not the one that received the heaviest coating. Thus, the network structure in pure β-lg gel is speculated to be more rigid. When a globular protein, like β-lg, is heated in solution under controlled conditions, it starts to unfold and lose the secondary structure, then gels (Kavanagh, Clark, & Ross-Murphy, 2000). A previous study indicated that the β-lg protein contained a subdomain with a highly ordered resistant β-sheet core in acidic solution (Molinari et al., 1996). It decreased the flexibility of the gel structure. Under a similar acidic condition, Aymard, Durand, and Nicolai (1996) discovered that β-lg tended to form rod-like structure gel but not globular structure at pH 7. Unlike globules in aggregates, the rods were speculated to be built by exposed disulphide exchange (Aymard et al., 1996). These factors resulted in the well-defined long linear aggregates were formed in the acid β-lg gel. Therefore, the network structure became stronger with this special molecule form. However, most previous experiments were operated in less than 100 °C conditions, much lower than the frying temperature in our research, which could affect the gel structure.
Since WPI, β-lg showed effect on oil reduction in the current research, their applications may improve the quality of people’s life via offering healthy food. Cutting calorie intake from fat could decrease the threatening of obesity and the happening of related chronic diseases. What’s more, more need in food production means more usage of these by-products of cheese production and infant formula production.

Conclusion

This study attempted to identify the effects of β-lg and α-la in reducing oil in deep-fried breaded chicken pieces. These proteins were applied to the substrate as an additional dip at 10% (w/w) in the final coating process before frying. Whey protein isolate (WPI) has been observed to work as an oil barrier in fried food probably due to its gelation properties (Mah et al., 2008). First and foremost, this research confirmed the ability of WPI to reduce oil absorption in fried chicken. This research also provides strong evidence that the protein responsible for oil inhibition in these systems is β-lg. The 10% β-lg treatment significantly reduced lipid content and caused increased moisture content. The β-lg dip produced similar coating pickup, produced samples that were lighter and more yellowish in color, and did not affect texture. The 10% α-la dip did not reduce oil content significantly but maintained moisture in the chicken pieces. There were no other significant differences from the undipped control. Nevertheless, this group had significant lower lipid content than the negative control (100% water). Taken together, this research supports the conclusion that the agent responsible for WPI inhibition of oil absorption during deep frying is β-lg.
Since WPI, β-lg showed effect on oil reduction in the current research, their applications may improve the quality of people’s life via offering healthy food. Cutting calorie intake from fat could decrease the threatening of obesity and the happening of related chronic diseases. What’s more, more need in food production means more usage of these by-products of cheese production and infant formula production.

**Future Studies**

The texture analysis in this research was produced from instrumental measurements. But in order to access consumers’ acceptation, sensory analysis is necessary. The psychological and methodological factors cannot be calculated and analyzed during the mechanical test (Meullenet, Lyon, Carpenter, & Lyon, 1998). The real mouth sensation and flavor are the main parts of the quality of deep-fried chicken pieces.

In addition, future studies could maximize the β-lg content to achieve the highest lipid inhibition. Different levels of β-lg and α-la should be investigated to their effects on oil reduction. However, the maximum content should be reasonable for factory production. The prices of pure β-lg and α-la are not as cheap as WPI at this moment. What’s more, isolating the other components of WPI that work together with β-lg to cause oil inhibition in fried meat products would be beneficial.

The application can be expanded to include more food materials such as the thousands of fried snacks in the fast food market, such as beef, potato, and cheese. Fried food is also an important part in preparing home cooking meal. If β-lg and α-la can be used to supply low-fat food, it may be easier to achieve a healthy diet.
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Appendix A: Random Sequences in Replications

I. Produce random number in Microsoft Excel (Microsoft Office, Version 14.0 2010, Microsoft Co., Redmond, WA):

1. Enter item names in the first column. Such as group 1, group 2.

2. Select first cell in the second column. Press the “Insert Function” button “fx” then select the function RAND in “Select a function” area. Its definition is “Returns a random number greater than or equal to 1 and less than 1, evenly distributed (changes on recalculation)”. Then press OK.

3. There may be a small window named “Function Arguments”. Press “OK”. A random number will fill this cell.

4. Select the rest cells in the second column when a “+” appears at the right bottom of the filled cell. Then all the cells in the second column have random number.

5. Move to another field in the Excel which does not overlap the rows in the table above.

6. Reenter item names in the first column in the new place.

7. Paste the random numbers as their original position in the table above without any formats. Make it a new two-column table.


9. Select the random number column in “Sort by”; Values in “Sort On”; Smallest to Largest in “Order”. Then press “OK”.

10. The order of the item names in is changed as a random sequence.

II. Random sequences in four replications.

1. Experimental group codes table

<table>
<thead>
<tr>
<th>Experimental groups</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undipped control</td>
<td>C1</td>
</tr>
<tr>
<td>100% Water control</td>
<td>C2</td>
</tr>
<tr>
<td>10% WPI</td>
<td>WPI</td>
</tr>
<tr>
<td>10% β-Lg</td>
<td>T1</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (3:1)</td>
<td>T2</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:1)</td>
<td>T3</td>
</tr>
<tr>
<td>10% Protein composed of β-lg:α-la (1:3)</td>
<td>T4</td>
</tr>
<tr>
<td>10% α-La</td>
<td>T5</td>
</tr>
</tbody>
</table>

2. Random sequences in four replications table

<table>
<thead>
<tr>
<th>Replication 1</th>
<th>Replication 2</th>
<th>Replication 3</th>
<th>Replication 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>T1</td>
<td>T3</td>
<td>T5</td>
</tr>
<tr>
<td>T4</td>
<td>C1</td>
<td>C2</td>
<td>WPI</td>
</tr>
<tr>
<td>T1</td>
<td>T2</td>
<td>T4</td>
<td>C2</td>
</tr>
<tr>
<td>WPI</td>
<td>T5</td>
<td>T5</td>
<td>T4</td>
</tr>
<tr>
<td>C2</td>
<td>WPI</td>
<td>C1</td>
<td>T3</td>
</tr>
<tr>
<td>T5</td>
<td>C2</td>
<td>T2</td>
<td>T1</td>
</tr>
<tr>
<td>T3</td>
<td>T4</td>
<td>WPI</td>
<td>C1</td>
</tr>
<tr>
<td>C1</td>
<td>T3</td>
<td>T1</td>
<td>T2</td>
</tr>
</tbody>
</table>
Appendix B: Figure Permission

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