This thesis titled
A Study on the Effect of Whey Protein Isolate as an Ingredient-Based Oil Reduction
Strategy in Fried Food

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Abstract

PETTIT, KATHERINE L., M.S., May 2014, Food and Nutrition Sciences

A Study on the Effect of Whey Protein Isolate as an Ingredient-Based Oil Reduction Strategy in Fried Food

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The development of deep-fried chicken samples that contain less than 35% of calories from fat would allow consumers to enjoy the taste and texture that is characteristic of fried food while still meeting the dietary guidelines set by the Institute of Medicine. This study investigated the effectiveness of whey protein isolate (WPI) in reducing the oil content of deep-fried chicken samples when used as a postbreading dip and also as a batter ingredient. Chicken samples were cut into 10 ± 1 g pieces from whole, white meat chicken breasts. The samples were dusted with wheat flour, battered, breaded with Japanese Bread Crumbs, dipped in a 10% of WPI, and fried in vegetable oil at 375°F for 2 minutes. Control samples were not subjected to the 10% WPI dip and were instead fried immediately after breading. Three main effects were studied: WPI postbreading dip (no dip, dip), batter pH (2 & 6), and percent of WPI added to the batter (0, 5, & 10). In terms of lipid content the most effective treatments, defined as samples that contained significantly lower lipid than the control, were samples that were battered with a batter at pH 2 containing 0, 5, and 10% WPI which were dipped in the 10% WPI solution. These samples contained 37%, 37%, and 36% calories from fat, respectively, compared to the control which contained 40% calories from fat. Moisture content of the samples was increased by the application of the WPI postbreading dip. Texture and color
were also significantly affected by the use of WPI. The negative control was lighter than the dipped sample with 10% WPI in the batter at pH 6. Yellowness increased between dipped vs. undipped samples. Lowering the batter to pH 2 increased the hardness, crust fracture force, and total work of the fried samples compared to samples that were coated with batter at pH 6. The results of this study show that WPI, as an ingredient, is effective at reducing the fat content of deep-fried chicken samples. WPI was most effective, i.e., the highest lipid reduction was observed, when the both the batter containing WPI and the WPI dip were at pH 2. If the performance of WPI is optimized, it has the potential to produce chicken samples with 35% of calories from fat or less.
Dedication

For my wonderful and supportive husband, Nick,
my parents who have always been there for me,
and my four legged children.
Acknowledgments

I would like to acknowledge the following individuals: Dr. Robert G. Brannan, Francis McFadden, Dr. Diana Schwerha, Camille Mihalic, Dr. Darlene Berryman, Dr. Jennifer Horner, Cara Acksel, Silvana Duran Ortiz, Trisha Peters, Elizabeth Smith, Teena Stambaugh, Sumali Hewage, and all of my other friends, colleagues, and professors at Ohio University. I am extremely thankful for their guidance and support throughout my M.S. studies and in the production of this thesis.
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List of Acronyms and Abbreviations

*BMI:* Body mass index

*BSA:* Bovine serum albumin

*CDC:* Centers for Disease Control and Prevention

*CMC:* Carboxymethyl cellulose

*EA:* Egg albumin

*HDL:* High-density lipoprotein

*HPMC:* hydroxypropyl methylcellulose

*JBC:* Japanese breadcrumbs

*LDL:* Low-density lipoprotein

*MC:* Methylcellulose

*NHANES:* National Health and Nutrition Examination Survey

*SPI:* Soy protein isolate

*TPM:* Total polar material

*USDA:* U.S. Department of Agriculture

*WPI:* Whey protein isolate
Chapter 1: Introduction

This research investigated the effectiveness of whey protein isolate (WPI) in reducing the fat content of deep-fried, battered and breaded, chicken samples. WPI was incorporated into a standard batter and into a 10% WPI postbreading dip. Without the WPI treatment, deep-fried, battered and breaded chicken typically contains more than 50% calories from fat, although in this study the battered and breaded chicken samples contained around 40% calories from fat. For the WPI treatment to be successful, the fat level in deep-fried, battered and breaded chicken would have to be reduced to 35% of calories from fat.

According to the Institute of Medicine (2002), adults and children over the age of 4 should consume no more than 35% of calories from fat. Fat consumption over this level can lead to health problems such as obesity (Ghidurus, Turtoi, Boskou, Niculita, & Stan, 2010). Over 33% of U.S. adults are considered obese and in 2012 there was no state with an obesity rate below 20%. Obesity-related diseases include heart disease, stroke, type 2 diabetes, and certain types of cancer (Centers for Disease Control and Prevention [CDC], 2009-2010a). Childhood obesity is a problem in the United States; it has more than tripled over the last 30 years. Children who are obese are at a greater risk for bone and joint problems, sleep apnea, and social and psychological problems such as stigmatization and poor self-esteem. Furthermore, children who are obese are more likely to be obese as adults. This puts them at risk for more serious conditions such as heart disease, diabetes, and some types of cancer (CDC, 2009-2010b).
Fried foods contain high levels of fat, sometimes reaching one third of the total product by weight. Fried foods have become extremely popular, not only in the United States, but around the world (Barbut, 2013). Deep frying is a major operation used in food production and deep frying within the fast food industry produces billions of dollars worldwide (Mallikarjunan, Ngadi, & Chinnan, 2004).

Methods have been developed to reduce the fat content of fried foods. Some are simple measures are shaking and draining of the freshly fried food and monitoring proper frying time and temperature (Mellema, 2003). Oil quality and composition also affect the amount of oil absorbed during deep frying (Moreira, Sun, & Chen, 1997). Ingredients incorporated into coating systems have been shown to affect the amount of oil absorbed during deep frying. Edible food coatings such as proteins and hydrocolloids have been used successfully to reduce the oil uptake of fried foods such as chicken, potato strips, meatballs, chickpea dough, tortilla chips, and donuts (Balasubramaniam, Chinnan, Mallikarjunan, & Phillips, 1997; Mellema, 2003). Alternative frying methods are needed which will create a chicken sample with 35% of calories from fat or less while also appealing to industrial production, thereby allowing such processes to be commercialized (Brannan et al., 2014)

Previous research has utilized WPI to reduce oil absorption in deep-fried chicken samples. Our laboratory has achieved a chicken sample with 38% reduction in fat by using a postbreading dip consisting of 10% WPI at pH 2 (Mah, Price, & Brannan, 2008), and provided evidence that β-lactaglobulin, the principle protein in WPI, is responsible for the oil inhibition properties of WPI (Yuan, 2012). The fat content of deep-fried
breaded chicken was reduced using WPI as a dip prior to breading and frying (Kurt & Kilincceker, 2011). Another group found that 3% WPI added to the batter of deep-fried chicken samples resulted in a reduction of oil absorption, which and the authors attributed to the thermal gelation and film forming properties of WPI (Dogan, Sahin, & Sumnu, 2005).

Statement of the Problem

Consumption of fried food can lead to a higher amount of calories from fat consumed than recommended by the Institute of Medicine. Different approaches can be employed to decrease the amount of calories from fat in the American diet. One approach is to replace fried and other junk food in our diets with more healthy options like fruits and vegetables. This study employs a different approach by attempting to reduce the amount of calories from fat in fried food to 35% or less, adding them to list of food that meet dietary recommendations. Although WPI has been effective as a postbreading dip in reducing the fat content of fried foods, a fat content below 35% calories from fat has not been achieved. Therefore, the objective of this research was to produce reduced fat deep-fried chicken samples using WPI that meet the dietary recommendations.
**Research Questions**

Table 1

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<td>How does increasing the concentration of WPI (0%, 5%, and 10%) in a standard batter recipe affect the oil absorption in deep-fried chicken samples?</td>
<td>Increasing the concentration of WPI in a standard batter recipe will decrease the fat content of deep-fried chicken samples.</td>
</tr>
<tr>
<td>What is the synergistic effect of a standard batter containing WPI (0%, 5%, and 10%) and a post-breading dip of 10% WPI on the oil absorption in deep-fried chicken samples?</td>
<td>Chicken samples with increasing concentrations of WPI in a standard batter which are also subjected to a 10% WPI postbreading dip will absorb lower amounts of fat.</td>
</tr>
<tr>
<td>How does adjusting the batter pH to pH 2 affect the amount of oil absorbed by deep-fried chicken samples?</td>
<td>Adjusting the batter to pH 2 will decrease the amount of oil that is absorbed by deep-fried chicken samples.</td>
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<td>What affect does WPI have on the texture and color of deep-fried chicken samples?</td>
<td>Color will be darker with increasing amount of WPI. Increasing amounts of WPI will also cause an increase in the hardness of the chicken samples.</td>
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**Significance of Study**

Many benefits would be achieved by reducing the fat content of deep-fried chicken samples. If a percentage of 35 or less of calories from fat is achieved, Americans would be able to consume the fried foods they enjoy while meeting the guidelines set by the Institute of Medicine (Institute of Medicine, 2002). Schools would be able to serve deep-fried chicken samples while meeting the standards set by the U.S. Department of Agriculture (USDA). Serving foods that have the same texture and mouth-feel that appeal to consumers is a good way to promote healthy eating while still allowing them to enjoy
their food. Reducing the fat content of chicken samples would also reduce the total amount of calories consumed. This is an important factor when attempting to reduce the risk for certain diseases including heart disease, stroke, certain cancers, diabetes, and obesity (CDC, 2009). If this method was used across the country instead of the standard method of frying food, the total number of calories reduced would be vast. Thus, this study could have a potentially positive effect on the health of our nation.

Limitations

There were factors in this study that affected the oil absorption of deep-fried chicken samples. These factors include the shape of the samples, increased viscosity of the batter, and degradation of the frying oil. Chicken pieces were cut from whole, white meat, all natural chicken breasts. Each piece was weighed (10 ± 1 g) to ensure for substrate uniformity; however, it was not possible to ensure that every piece was the exact same shape. Batter viscosity was tested for each batter prepared. Batter thickness could have changed slightly throughout the process due to temperature changes, evaporation of water, or addition of moisture from the chicken. Japanese bread crumbs (JBC) were used to bread the chicken before frying. The bread crumbs were used as delivered, i.e., they not sieved to remove excessively small or large particles.

Frying oil degrades with continuous frying, causing the buildup of total polar material (TPM). The frying oil was seeded with partially degraded oil before the first batch of chicken samples was fried, which is common practice with new oil. TPM increased over time as more chicken samples were fried and thus the first batch of samples was fried in oil that contained less TPM than the last batch. However, it is
unlikely that the amount of TPM increased to a point that it affected oil absorption of the food, as shown in an earlier study (Mah et al., 2008).

Lipid extractions on ground chicken samples were performed using the Folch Method (Folch, Lees, & Sloane Stanley, 1957). With each extraction a small amount of lipid was left behind to avoid the pickup of ground chicken or water. This is true of each sample and with 3 successive washings of the chicken with solvent it is improbable that the lipid not extracted is significant. It is unlikely that any of these limitations affected the outcome of the variables studied.
Chapter 2: Literature Review

Introduction

**Fried food consumption and average intake of dietary fat.** According to the Institute of Medicine (2002), adults and children over the age of 4 should consume no more than 35% of calories from fat. Consumption of fat is important to our health and certain fatty acids are essential because they cannot be produced within the body and must be obtained by diet (Ducheix et al., 2013). Fats are required by the human body to absorb fat soluble vitamins; A, D, E, K, and carotenoids (Lovejoy, 2010). Fats are important to brain function (Miyake et al., 2010). Fat within foods is desirable because it improves the texture and mouth feel of food, carries aromatic compounds, and serves as a vector for flavor (Yogesh, Ahmad, Manpreet, Mangesh, & Das, 2013).

Many studies have noted that Americans have reduced their percentage of calories of fat over the last 30 years. This can be attributed to the fact that the overall amount of calories consumed has increased. Intake of added fats by the way of processed foods and cooking oils has grown by 63% from 1970 to 2005 (Lovejoy, 2010). This overall increase of calories consumed can be attributed to more eating occasions, affinity for foods that have a higher energy density, as well as an increase in portion sizes (Duffey & Popkin, 2011). Young children have the ability to regulate the amount of food they eat even when they are offered larger portion sizes than necessary to negate their hunger. Some research has shown that after the age of 2 the amount of food intake increases with the portion size offered, which could be a contributing factor to childhood obesity (Ramsay, Safaai, Croschere, Branen, & Wiest, 2013).
Overconsumption of fat can lead to health problems, especially in developed countries, due to high consumption of calories from fat (Mehta & Swinburn, 2001). Although the amount of solid fat consumed by children and adolescents has decreased between 1994-1998 and 2009-2010, the amount still exceeds the recommended amount by 18-20% of total energy intake (Slining & Popkin, 2013). According to the National Health and Nutrition Examination Survey (NHANES), the mean fat intake is 33.6% of total calories from fat (Eckel et al., 2009). Consumption of dietary fat at the higher end of the recommended range (20-35% calories from fat) and above can make it difficult for consumers to limit their intake of saturated fat as well as limit their overall energy intake (Lovejoy, 2010). More than one third (35.7%) of adults and 18% of children aged 6-11 living in the United States are considered by the CDC to be obese and at risk for chronic disease. One of the main causes for chronic diseases is poor nutrition. (CDC, 2009-2010a). According to the CDC, chronic disease is the public health challenge of the 21st century. Among the diseases listed are heart disease, stroke, cancer, diabetes, and obesity.

Studies have shown that replacing saturated fat in the diet with polyunsaturated fat can reduced the risk of coronary heart disease (Jakobsen et al., 2009). The Westernized society can be characterized by an increased ω-6 to ω-3 fatty acid ratio. This unbalanced ratio could be contributing to the increased risk for some chronic diseases including heart disease and cancer (Simopoulos, 2010). Consumption of a specific ω-6 fatty acid, arachidonic acid, has been positively correlated to the development of Parkinson’s disease (Miyake et al., 2010). Arachadonic acid, found in many plant oils, can lead to inflammation and thrombosis. Arachadonic acid also produces
endocannabinoides, which can be a contributing factor to obesity and inflammation. On the other hand, consumption of foods high in an ω-9 fatty acid called oleic acid has been correlated to improved insulin sensitivity, lowered LDL (low-density lipoprotein), and increased HDL (high-density lipoprotein) (Hostmark & Haug, 2013).

A high-fat diet can lead to obesity which may have adverse effects on metabolism and an increased risk for developing heart disease and type 2 diabetes (Birse et al., 2010). The obesity rate in the United States has increased by 37% between 1998 and 2006. Medical spending per capita attributable to obesity is also on the rise. Spending by an obese person compared to someone of normal weight was 42% higher in 2006 (Finkelstein, Trogdon, Cohen, & Dietz, 2009). Eating meals prepared outside of the home has been shown to contribute to weight gain. Foods consumed away from home are often higher in calories and fat, further contributing to the development of obesity. Correlation between weight gain and eating out was mainly seen when fat food restaurant were visited more than once per week (Bezerra, Curioni, & Sichieri, 2012). One study found that one third of adolescents could be found eating at a fast food restaurant on any day. Weekly visits to a fast food restaurant have been found to show a 0.2-unit rise in Body Mass Index (BMI) in youth (Davis & Carpenter, 2009).

As consumers have realized that a diet high in fat can lead to health risks they have searched for ways to reduce their calories from fat. This need has brought about the development of reduced fat food products (Lim, Inglett, & Lee, 2010). In a study done by the American Dietetic Association, 75% of consumers claimed that they were actively purchasing low-fat food products (Plotnikoff et al., 2009). From a national sample, 48%
of participants agreed that specific foods were either good or bad for their health. Foods that were perceived to be high in fat were thought to be unhealthy whereas foods that were labeled “low-fat” were thought to be healthier. It was found that study participants ate more candy when they believed they were consuming “low-fat” chocolate, however it was not enough to reach statistical significance (Ebneter, Lather, & Nigg, 2013). The desire for these reduced fat foods is clear; however, the popularity of fast food restaurants and fried food remains steady. Determining a method of reducing the fat content of fried food could be one way of lowering the amount of calories from fat in the American diet.

Coated foods: Batters and breading. Fried foods are extremely popular not only in the United States, but across the globe (Barbut, 2013). For some time the most well-known examples of coated and fried foods included items such as chicken, fish, and onion rings. Cheese sticks and battered and breaded vegetables have become popular as well (Fiszman, Sanz, & Guerrero-Legarreta, 2010). Coatings are widely implemented in deep-fried food as they enhance the look, flavor and texture of the food. They also give the food an appealing browned color and create a crispy crust (Dogan et al., 2005). The well-liked flavor of fried food is produced via Maillard reactions within the crust (Mellema, 2003).

The process of frying food begins with the substrate. The substrate can be meat, vegetables, cheese, or other food items. According to North American equipment manufacturers, poultry is currently the most produced battered and breaded food. The first step of the breading procedure is the predust in which the substrate (usually meat) is dredged in flour. Although flour is the most common, other ingredients, such as starches
and gums, can also be used. The predust increases batter adhesion because it absorbs some water on the surface of the meat. Next the substrate is dipped in the batter. Flour is the most common and basic ingredient in the batter. The amount and type of flour used affects adhesion, viscosity, color after frying, and oil absorption. Other batter ingredients can include dextrins, protein, and fiber. The food is then placed in the breading which is usually some type of breadcrumbs (Fiszman et al., 2010). There are two types of coating systems. Cohesive coatings bind mostly to themselves and not to the substrate which they are coating, whereas adhesive coatings bind mostly to the substrate which they are coating (Han, 2005).

**Popularity of chicken.** Americans consume more chicken than any other country in the world. At 83.6 pounds per capita, it is the leading protein in the United States. Chicken consumption in the United States has increased from 33.7 pounds per capita in 1965 to an estimated 81.4 pounds per capita in 2013. In 2010 56% of chicken was sold in grocery stores and 44% was sold within the food service industry. The fast food industry consumed 57% of the total food service portion of the market segment for chicken (National Chicken Council, 2012).

Chicken samples are one of the most popular fried foods served at fast food restaurants (Soorgi, Mohebbi, Mousavi, & Shahidi, 2012). The market for battered and breaded chicken products has been growing over the last few decades because the products are quite appealing. They are processed and then frozen. They can be quickly prepared by consumers in an oven or by frying. Consumers are looking for their chicken samples to be hot, moist, flavorful, and have a crispy outer crust (Fiszman et al., 2010).
Oil Uptake: Theories and Mechanisms

**Process of deep-fat frying.** The process of deep-fat frying is complicated. It involves the transfer of heat and mass in food with a porous surface. Water within the food vaporizes and causes violent bubbles to escape from the food. These bubbles cause heat convection within the frying oil (Lioumbas, Kostoglou, & Karapantsios, 2012). When food is first submerged in heated frying oil, the surface of the food quickly heats to the temperature of boiling water. The surface temperature of the food then rises above the temperature of boiling water and a crust begins to form (Farid & Kizilel, 2009). The stages of frying have been described as follows: (a) initial heating, (b) surface boiling, (c) falling rate, and (d) bubble end point (Farkas, Singh, & Rumsey, 1996). During initial heating, the surface temperature of the raw food rises from its initial temperature to the temperature of the boiling surface water. Convection occurs within the frying oil and causes heat to be transferred from the frying oil to the food. This phase of initial heating is short, and the amount of water released from the food is insignificant. The second phase, surface boiling, begins with the increase of the temperature on the surface of the food above the boiling of the surface water. The water vaporizes and escapes from the food. These violent bubbles cause turbulence within the surrounding oil. This causes the rapid bubbling that can be seen during the early portion of frying. The third stage, referred to as falling rate, is the longest of the four stages. This is when the most moisture is lost from the food and the crust thickens. The core of the food nears the temperature of the boiling water located there and the mass transfer continues to decrease as more water is lost. The fourth and final stage described by the authors is bubble end point. This refers
to the complete loss of water from the food (in the case of French fries or potato chips) or a decrease in the transfer of heat between the crust and the core of the food (Farkas et al., 1996).

**Oil absorption and mechanisms of oil uptake.** There are three possible mechanisms of oil uptake in deep-fried food described. They are titled water replacement, cooling-phase effect, and surfactant theory (Brannan et al., 2014; Dana & Saguy, 2006). Although each will be explained in detail, it is likely that these mechanisms are not independent of one another such that each may be contributing to the totality of oil absorption during frying.

**Water replacement.** When food is placed in heated frying oil, water evaporates quickly. Water escapes through cracks and crevices within the structure of the food. However, not all water vapor escapes and the temperature of the portion remaining rises above its vaporization point producing superheated vapor. The superheated vapor makes the structure of the material more porous, leading to the development of voids throughout the material (Ziaiifar, Courtois, & Trystram, 2010). The development of pores left by escaping water allows oil to enter the food through these pores (see Figure 1). As water within the food continues to boil, surface drying occurs. The water replacement mechanism can explain why moisture loss is inversely proportional to oil uptake. Portions of the food which have higher moisture content will also show higher oil absorption (Mellema, 2003). The uptake of oil also helps the food maintain its structure and avoid shrinkage. Batter formulation has been found to significantly affect porosity development as well as the number and size of the pores (Adedeji & Ngadi, 2011).
details on the effect of batter on oil absorption is found in the section titled *Coated foods: Batters and breading*.

*Figure 1.* Diagram of Dana and Saguy’s water replacement theory.

*Cooling-phase effect.* It has been shown that the majority of oil uptake occurs after the food is removed from the frying oil. When frying has commenced, food is removed from the hot oil and begins to cool. The water vapor within the food condenses and creates a lowered internal pressure. This acts as a vacuum which sucks oil on the surface of the food into the pores created by the escape of moisture.

The formation of the crust during the frying process and the viscosity of the frying oil are two factors that affect the cooling-phase effect. Crust formation is a very important factor in the amount of oil that is absorbed into the food, because most oil is located on the surface and within the crust of the food. Another reason fat can accumulate at the surface is due to hardstock or solid fat. The frying oil can consist of a portion of
this fat which solidifies upon cooling. This makes the fat harder to drain from the surface of the food after it is removed from the frying oil and therefore increases the overall fat content of the food (Mellema, 2003). The majority of the total fat content, 80%, was found at the surface of deep-fried tortilla chips and 64% of the surface oil was found to later be absorbed into the product during cooling (Moreira et al., 1997). Oil viscosity also plays an important role in controlling the amount of oil that is absorbed during cooling. Oil viscosity increases as frying time is lengthened (Dana & Saguy, 2006). As oil is heated it undergoes specific reactions which increase oil viscosity (Guillien & Uriarte, 2012). This increase in viscosity can cause more oil to be absorbed simply because oil with a lower viscosity is easier to drain from food after frying (Mellema, 2003).

**Surfactant theory.** Continuous heating of frying oil can bring about unfavorable changes in the composition of the oil. Before any food is fried in the frying oil, it is comprised of higher than 95% triglycerides (Juarez, Osawa, Acuna, Samman, & Goncalves, 2011). As the oil is heated and frying begins, water vapor that escapes from the food causes hydrolytic reactions in the triglycerides producing free fatty acids, monoglycerides, diglycerides, and glycerol (Dana & Saguy, 2006). These compounds are polar due to the exposure of their polar hydroxyl groups and are referred to collectively as TPM. Of these, monoglycerides and diglycerides are polar compounds that exhibit surface-active properties. The incidence of foaming within the frying oil is increased by the degradation of the oil and subsequent accumulation of surface-active agents. A food foam is defined as a colloidal system with a gaseous discontinuous phase dispersed inside a liquid continuous phase. In this case, the water vapor escaping from the product acts as
the discontinuous phase and the oil acts as the continuous phase. Foaming is aided by the emulsification properties of the surface active mono- and diglycerides. Foam formation increases the rate of hydrolytic reactions and the rate of decomposition of the oil (McWilliams, 1989). The surfactants that are formed lower the interfacial tension between the frying oil and the surface of the food which is responsible for increasing oil uptake as well as changes in the food both on the surface and internally (Dana & Saguy, 2006; Kalogianni, Karapantsios, & Miller, 2011). The increase in surfactants and TPM also increases the viscosity of the frying oil which is mentioned above as a cause of increased oil uptake in the cooling-phase effect. In support of this theory, research shows that the higher the level of TPM (as measured by liquid absorption chromatography) the lower the quality of the frying oil.

One theory alone probably does not describe the total oil uptake during deep frying. The water replacement theory accounts for oil that is absorbed as water within the food vaporizes, leaving voids for the oil to enter. The cooling phase effect describes oil that is absorbed after the food is removed from the oil due to overpressure created within the pores of the food by the vaporization of water. The surfactant theory relates surface active agents that form as oil degrades to the increase in oil uptake (Dana & Saguy, 2006).

**Variables Influencing Oil Uptake**

The amount of fat absorbed by a food during frying can depend on many different variables. Some of these are related to the food itself; type of substrate, moisture content, porosity formation, and surface area are all examples of intrinsic variables (Mellema,
2003; Thanatuksorn, Kajiwara, & Suzuki, 2010). Extrinsic variables influencing oil uptake include frying time, temperature of the frying oil, composition of the frying oil, amount of drainage after frying (Mehta & Swinburn, 2001), and ingredients that inhibit oil uptake.

**Intrinsic variables influencing oil uptake.** The amount of oil absorbed by a food during frying is largely determined by the moisture content of the food, specifically the crust. The larger the amount of water stored in the surface of the food the larger the amount of oil is absorbed. This can be explained by the water replacement theory mentioned previously (Dana & Saguy, 2006). As water vapor escapes from the substrate and crust, it creates voids into which oil can enter. The more water in the food the more voids will be created and the more oil will enter (Mellema, 2003).

However, in a recent paper from our laboratory, Brannan, Myers, and Herrick (2013) suggested that it is the location of the water on the substrate that relates to oil uptake. Chicken fritters were battered and breaded and the fried samples were tested for moisture and lipid content. Fritters that were tested using a postbreading dip of 11% dried egg white solution were compared to an undipped control. In the control fritters, which were not dipped, 62.2% of the moisture that was lost during frying could be accounted for by the addition of moisture in the batter and breading. The remaining 37.8% of moisture lost was attributed to the moisture naturally occurring in the chicken itself that vaporized and escaped through pores in the crust. Almost all of the moisture loss within the fritters subjected to the dried egg white dip theoretically could be attributed to the addition of the moisture within the coating, leaving a small amount lost from the chicken.
The authors speculated that the low amount of water that vaporizes from the chicken itself was responsible for the oil inhibition effect found in these samples. Because there was no linear relationship between oil uptake and the moisture present in the postbreading dip, the authors attributed the oil inhibition to the moisture located on the surface of the battered and breaded chicken. In a previous study, a 17.5% lipid reduction was found using only pH adjusted water as a postbreading dip for ground chicken patties coated with crackermeal, which lends support to the theory established by Brannan et al. (2013). The vaporization of moisture within the crust and the substrate can affect the porosity of the sample which also has an effect on oil uptake (Brannan et al. 2013).

Pores are created during frying by escaping water vapor. Different aspects of pore formation, including pore size, shape, and interconnectivity can affect mass transfer during frying. Coatings applied to foods can influence the development of porosity and in turn oil uptake. Figure 2 shows 3-D images of chicken samples coated with different batter formulations. They show evidence that batter formulation is correlated with porosity. Figure 2B shows that a hydrocolloid, carboxymethyl cellulose (CMC), within a batter composed of 100% flour caused a decrease in the amount of pores created during frying. The batter containing 30% rice flour (see Figure 2C) increased pore development. Increasing concentrations of rice flour (see Figures 2C-F) show a progressive increase in the amount of pores that were developed (Adedeji & Ngadi, 2011).
Substrates that have a larger surface area absorb more oil. Oil absorption increases linearly as surface area increases. Surface roughness creates a larger surface area and therefore also increases oil absorption. The density of the food has also been related to oil uptake. This could possibly be due to the fact that density has been correlated to porosity (Saguy, Ufheil, & Livings, 1998). The portion of the food that determines the amount of oil absorbed is the crust. It is well known that almost no oil is absorbed into the core of the food (Mellema, 2003).

**Extrinsic variables influencing oil uptake.** Extrinsic variables influencing oil uptake are considered to be independent of the food being fried. These variables include frying time, frying temperature, oil composition, and pre- and posttreatment of the food (Wang, Jiang, Zhu, & Hou, 2013). Oil absorption during frying can be optimized if food
is fried at the correct temperature. Temperatures which are too high (above 185 °C) cause the oil to degrade quickly. It can also cause the crust to become overly browned or burned while the core does not become fully cooked. Low frying temperatures (below 170 °C) may not allow for crust formation. This could lead to more oil being absorbed into the core of the food (Mehta & Swinburn, 2001). A significant difference (p = 0.022) was found in potato fried at 155 °C and potato fried at 170 °C and 185 °C. Higher frying temperatures are generally believed to lower oil absorption. However, there was not a significant difference (p = 0.335) between potato fried at the two higher temperatures (Bouchon, Aguilera, & Pyle, 2003).

These higher temperatures allow for food to be cooked quickly so they would spend less time in the frying oil. Oil absorption has been found to increase with increased frying time. This could be due to the increase moisture loss with increased frying time (Lalam, Sandhu, Takhar, Thompson, & Alvarado, 2013). The theory is that shorter fry times would allow for less water to vaporize, decreasing porosity, and allowing less room for oil to enter the food (Saguy et al., 1998). Trans fatty acid content of deep-fried potatoes was found to increase with increasing frying time (Brannan et al., 2014).

Tortilla chips fried in fresh oil absorbed more oil during the cooling phase than tortilla chips fried in decomposed oil (1-2% FFA; 66% TPM), however the final oil content was not significantly different (Moreira et al., 1997). Other studies have found the TPM greatly affects the oil uptake in fried food. TPM plays a role in the surface tension between the oil and the food. This also is a factor in how much oil is absorbed (Saguy et al., 1998). The chips fried in the decomposed oil had higher amounts of oil at
the surface of the chip. The increased viscosity as well as the lowered surface tension of the oil caused by decomposition could make it difficult for the oil to drain off or to make its way to the core of the chip (Moreira et al., 1997).

Methods for inhibiting oil uptake in deep-fried foods. Research on reducing the fat content of deep-fried food has increased over the last 5 years (Mellema, 2003). Consumption of fried food has been linked to diseases such as obesity, diabetes, coronary heart disease, and certain types of cancer (Mehta & Swinburn, 2001; Varela & Fiszman, 2011). It is due to these health concerns that researchers began to develop ways to reduce the fat content of deep-fried food.

Because studies have shown that the majority of oil is absorbed after the food is removed from the frying oil, it is logical that handling of food postfrying can contribute to reducing the amount of oil absorbed. Proper draining and shaking of the food postfrying can reduce the amount of oil on the surface of the food and therefore the amount of oil available to be sucked into the voids created by the escape of water. Ensuring the correct oil temperature and frying time are important in controlling oil uptake.

Coatings and batters have also been shown to inhibit oil absorption. It is well known that oil uptake is a surface phenomenon and that oil absorption increases with increased moisture content of the food. Because most of the oil is absorbed into the crust, if the crust has a low moisture content, oil uptake, in theory, should be reduced (Mellema, 2003). Edible films and coatings to reduce oil absorption have been produced using nonprotein hydrocolloids as well as proteins such as whey protein, soy protein, and egg
albumin. The main function of an edible coating is to reduce the movement of water and, in turn, reduce the amount of oil absorbed into the food (Varela & Fiszman, 2011).

*Non-protein hydrocolloids.* Hydrocolloids, water-soluble polymers that increase viscosity or cause gel formation, are used extensively in the food industry due to the fact that they retain water in food systems (Soorgi et al., 2012). Nonprotein hydrocolloids are used in food production to increase the shelf-life of meat products as well as to help retain the structure of frozen foods (Varela & Fiszman, 2011). They can also function as thickeners, stabilizers, and emulsifiers (Kim, Lim, Bae, Lee, & Lee, 2011). They have been used to reduce the oil uptake in deep-fried food (Varela & Fiszman, 2011).

Hydrocolloids are usually applied as an aqueous solution. CMC was an effective barrier against oil absorption in deep-fried potato chips (Varela & Fiszman, 2011). Methylcellulose (MC) has shown a 49% reduction in the fat content of African cowpea paste-based food. In a study on fried chicken balls, HPMC was determined to increase the moisture content of the chicken by 16.4% while reducing the oil content of the chicken by 17.9% (Balasubramaniam et al., 1997). The main role played by these hydrocolloids is the reduction of oil uptake; however, they also play a role in viscosity control, batter adhesion (when used as a batter ingredient), and pick-up control (Varela & Fiszman, 2011). A 42 g/100 g reduction in oil content was discovered in the crust region of deep-fried chicken samples in which MC was used as a predust. Higher oil content was found in the crust region of the chicken sample than in the core (Lalam et al., 2013). A 41% fat reduction was found when potato strips were immersed in a 0.9% solution of guar gum prior to frying (Kim et al., 2011). A 55% fat reduction was found in deep-fried pastry
dough when immersed in a solution of gellan gum (Kim et al., 2011). A 43% reduction was found in the fat content of deep-fried banana chips. The chips were first blanched in a calcium chloride solution and then immediately placed in a CMC solution (Singthong & Thongkaew, 2009). A solution of HPMC was found to be effective at reducing the fat content of deep-fried chicken meatballs by 13.1 to 17.9% in the crust and 26.2 to 33.7% in the core. The HPMC solution was sprayed onto the meatballs and allowed to dry for 2 minutes before the meatballs were fried (Balasubramaniam et al., 1997). Cellulose derivative hydrocolloids have a high water retaining ability. This is useful in foods that are meant to stay moist, such as bread. However, it can be a problem when the end goal is a crispy outer crust in batter and breaded-fried food (Primo-Martín et al., 2010).

In addition to the peer reviewed literature, the patent literature is replete with examples of nonprotein hydrocolloids used as oil inhibitors in fried foods. It should be noted that the patent literature is not peer reviewed. Pregelatinized rice flour, phosphorylated rice starch, and pregelatinized acetylated rice starch were shown to reduce oil absorption in frying batters (U.S. Patent No. 6,224,921, 2001). Polydextrose has produced a 25.3% to 13.9% reduction in the fat content when it was added to the batter of deep-fried donuts (U.S. Patent No. 6,001,399, 1999). Cellulose fiber (3%) was shown to reduce the fat content of battered chicken strips by 30% and of fish fillets by 35% when it was used as a batter ingredient (U.S. Patent No. 5,019,406, 1993). Stypula and Buckholz found an inhibition in oil uptake using a combination of surface coating of surface coatings including starch, methyl cellulose, and xanthan gum (U.S. Patent No. 5,057,329, 1991). Hydroxypropylmethyl-cellulose, composed of 27-30% methoxyl and
4-12% hydroxypropyl, was shown to reduce the fat content by 52-59% when 10% (w/w) was added to the batter of fried food, i.e., chicken (U.S. Patent No. 4,900,573, 1990). A 31% reduction in oil content of deep-fried potatoes were found when they were dipped in a potato and corn starch slurry, typically 40% solids, before frying (U.S. Patent No. 8,163,321, 2012).

Other ingredients not derived from cellulose are also used in reducing the oil absorption in fried food. Alginate, an extract of seaweed, has the ability to form a coating via gelation. Pectinate coatings have similar characteristics to alginate. They both act as sacrificing agents to reduce moisture loss. CMC and pectin were both found effective in reducing the oil content of fried banana chips (Singthong & Thongkaew, 2009). Low-methoxyl pectin gels are created by the crosslinking of calcium ions (Varela & Fiszman, 2011).

Alginic ester (4% w/w), mixed into batters before frying, has been reported to retard oil uptake in deep-fried donuts by 47.6% (U.S. Patent No. 6,497,910, 2002). Calcium reactive pectin reduced the oil content of deep-fried chicken tenders by 4.2%. The chicken was breaded with calcium enriched cracker meal breading and then dipped into a 1% calcium reactive pectin solution (U.S. Patent No. 6,261,618, 2001). Chicken parts were dipped in a predust containing 7.51% calcium chloride. They were then coated with a batter which constisted of other ingredients as well as 1.5% sodium pectate. The chicken was allowed to sit for 10 seconds in order for the calcium and pectate to react and form a gel. It was then deep fried. This method proved effect at inhibiting oil uptake (U.S. Patent No. 5,753,286, 1998). Polysaccharide powder, with a preference for alginic
stated, produced a 14.8-36.6% reduction in fat content in fried food. The average particle size was 20 μm or less and egg white, whey protein, or wheat protein was added to the powder (U.S. Patent No. 7,820,217, 2010).

**Protein based coatings.** A 12.4% reduction of fat content was found in deep-fried cowpea paste when a solution of corn zein was applied via spraying. The cowpea paste was partially fried for 100 seconds before the coating was applied. This was necessary to set the structure of the paste. The coating was applied to the hot cowpea paste and blow dried for 15 minutes before the samples were fried again (Huse, Mallikarjunan, Chinnan, Hung, & Phillips, 1998). A 14.5% fat reduction compared to a control was found in deep-fried mashed potato balls when they were coated with corn zein before frying (Mallikarjunan, Chinnan, Balasubramaniam, & Phillips, 1997).

Dried egg white solution (11%) at pH 3 has shown a 34.5% lipid reduction when used as a post-breading dip for deep-fried chicken patties breaded with cracker meal. The authors attribute this fat reduction to the globular proteins in dried egg white that form a thermally induced gel (Myers & Brannan, 2012). Ovalbumin, which is the main protein of egg albumin, produced an approximately 30% fat reduction in deep-fried batter. The lipophobic nature of ovalbumin is attributed to the oil inhibition (Mohamed, Hamid, & Hamid, 1998). Brannan et al. (2013) found a 44% lipid reduction in deep-fried chicken fritters that were treated with an 11% dried egg white postbreading dip. The dried egg white dip was studied with the addition of corn and oat fiber. Both fibers produced a lipid reduction (24-32%), however it was not as substantial as the dried egg white dip alone (Brannan et al., 2014).
A 10% solution of SPI (pH 8) plasticized with 0.05% gellan gum applied to the surface of doughnut batter resulted in a 55.12% fat reduction when the samples were deep fried. It is important to note that the SPI coatings were allowed to dry in a convection oven before the samples were fried. The authors tested the film forming abilities of soy flour, soy protein concentrate, and SPI. Soy flour did not result in film formation due to its low protein content. Soy protein concentrate formed very weak films. SPI has the highest protein content and therefore formed the strongest films (Rayner, Ciolfi, Maves, Stedman, & Mittal, 2000). The addition of different proteins (EA, SPI, and WPI) to the batter of deep-fried chicken samples was tested. SPI produced a small decrease in oil content; however, of the three proteins tested, it proved the least effective at reducing oil absorption (Dogan et al., 2005). The effects of protein concentration (SPI and WPI) and pH on the performance optimization of deep-fried chicken meat have been studied. The chicken breast meat was cut into cubes and dipped into the protein solution, dipped in a dry commercial coating, and then fried. The optimized conditions were determined at 7.13 pH, 9.0% SPI, and 0.6% WPI. Variables considered in optimization were coating pickup, frying loss, yield, moisture, and fat content (Kurt & Kilincceker, 2011).

Proteins extracted from muscle of various species showed fat reduction when different types of meat were sprayed with the protein solution. A 26.4% fat reduction was found when the method was applied to battered and deep-fried chicken (U.S. Patent No. 7,163,707, 2007). Sodium casienate was found to exhibit a 26.9% reduction in the fat content of deep-fried chicken patties when applied and allowed to dry for 45 minutes.
before frying (U.S. Patent No. 5,527,549,1996). Gelatin solutions (25-35%) have been shown a 25 to 50% decrease in the fat content of deep-fried food when sprayed on and dried to form a film (U.S. Patent No. 4,511,583, 1985). A 17% fat reduction was found when sliced potato was coated with a 10% zein latex solution prior to frying. The solution was allowed to dry before the samples were fried (U.S. Patent No. 5,217,736, 1993).

Whey protein. WPI is a by-product of the cheese production industry and therefore it is relatively easy to come by and it is inexpensive (Fitzsimons, Mulvihill, & Morris, 2007; Ramos et al., 2012). It is composed of many different globular proteins, of which three dominate: β-lactoglobulin, α-lactalbumin, and bovine serum albumin (BSA). These globular proteins, especially β- lactoglobulin, can alter the pore structure of the food by forming a thermally induced gel. This gel is a lipid barrier. It keeps moisture from evaporating during frying and thus less oil will be absorbed into the food.

The isoelectric point of WPI is approximately 5.1 at which the protein has a neutral charge and more easily forms aggregates. At pH values away from the isoelectric point WPI has higher dispersibility and lower turbidity (Cornacchia, Forquenot de la Fortelle, & Venema, 2013). Before a protein can form a gel it must undergo a process called denaturation. Denaturation can be either reversible or irreversible. During this process the protein undergoes structural changes without breaking covalent bonds with the exception of the disulfide bridges (Gosal & Ross-Murphy, 2000). Disulfide cross-linking can also contribute to gel formation and is brought about at pH levels below the isoelectric point (Cornacchia et al., 2013). Denaturation can be brought about in several ways, most commonly via changes in temperature and pH. The addition of salts or
enzymatic action can also be used to denature proteins (Brannan et al., 2014). At temperatures above 60 °C whey proteins unfold and expose hydrophobic residues and sulfhydryl groups that were previously hidden. These residues associate with hydrophobic regions on other unfolded protein molecules. The denaturing phenomenon is well known and is a result of the disruption of inter- and intramolecular bonds. Hydrophobic interactions are thought to increase as temperature increases. When the temperature rises above approximately 70 °C, the hydrophobic interactions subside. The exposure of hydrophobic regions and sulfhydryl groups cause the proteins to become less stable and also cause a decrease in solubility (O'Loughlin, Murray, Kelly, FitzGerald, & Brodkorb, 2012). The hydrophilic regions attract and entrap water molecules forming a lattice structure called a gel (Brannan et al., 2014; Gosal & Ross-Murphy, 2000). Gels formed at the isoelectric point are opaque and some syneresis can be observed. Fibrillar networks are formed when protein gels at low pH values (i.e., 2).

A 37.5% reduction in oil content of battered and breaded deep-fried chicken patties was found using a postbreading dip of WPI. This study optimized the type of breading, WPI concentration, and pH of the solution. A 3 x 4 x 2 full factorial design was implemented with 3 levels of pH (2, 3, and 8), 4 levels of WPI concentration (0%, 2.5%, 5%, 10%), and two types of breading (crackermeal and Japanese breadcrumbs). The most successful reduction (37.5%) was achieved with a 10% WPI solution at pH 2 using Japanese breadcrumbs (Mah et al., 2008). A 30% fat reduction was found in deep-fried chicken strips with the implementation of a 10% denatured (D) WPI postbreading dip. This fat reduction reduced the amount of calories from fat from 33% to 25% (Dragich &
Krochta, 2010). A 48% reduction in the fat content of deep-fried chicken meatballs was found using a 3% solution of WPI (Al-Abdullah, Angor, Al-Ismail, & Ajo, 2011). A lipid reduction in deep-fried potato chips was achieved when a whey protein concentrate (WPC) solution was applied prior to frying. The WPC solution was allowed to dry for 30 minutes before the chips were fried. The fat content of WPC coated chips was 31.5% compared to the uncoated control which had a fat content of 33.1% (Aminlari, Ramezani, & Khalili, 2005). Chicken strips marinated in a solution of WPC produced a 34.8% fat reduction compared to control strips which were marinated in a solution containing no protein. After the marinade, the strips were breaded and fried (U.S. Patent No. 7,494,677, 2009). A WPC (2-55%) solution was found to reduce the oil uptake of fried “foodstuffs” by 5-35%. Oxidoreductase was added to the WPC to reduce browning (U.S. Patent No. 8,021,704, 2011).

The formula and composition of batters have been studied for their influences on moisture content, fat uptake, texture, viscosity, and thermal gelation (Adedeji & Ngadi, 2011). A fat reduction was found with addition of 1% and 3% WPI to the batter of deep-fried chicken samples. Researchers attribute this to the decrease in the porosity of the chicken samples caused by the heat induced gelation of the whey protein (Dogan et al., 2005).
Figure 3. Formation of heat set gels: model representing the possible aggregation steps in a typical heat-set globular protein such as b-Lg. Both dimer-monomer and monomer to denatured monomer equilibria are shown. At pH values well below the isoelectric pI fibrils are formed simply from aggregated monomers A. Under other conditions, B, a pre-aggregate is formed, which in turn leads to a more particulate gel. NB: the length scale for the individual pre-gel aggregate ‘units’ is different for cases A and B (Gosal & Ross-Murphy, 2000). Copyright 2000 by Elsevier. Reprinted with permission.

WPI has been used as a dip as well as an ingredient in a batter formulation (Dragich & Krochta, 2010). Water and fat migration throughout the product differ with
differing applications of WPI (Mallikarjunan et al., 2004). As previously discussed, in the section titled *Intrinsic Variables Influencing Oil Uptake*, surface moisture plays a large role in the amount of oil that is absorbed during frying (Mellema, 2003). Coating the surface of the food with a substance that has a low moisture content, moisture barrier properties, or is thermogelling or cross-linking can be one way to keep moisture in the product while inhibiting oil uptake (Mallikarjunan et al., 2004).

**Sensory Characteristics of Reduced Fat Chicken Samples**

When producing a deep-fried food product with reduced amounts of fat it is important to consider health, as well as sensory aspects (Arc a, Errero, Bértola, Martino, & Zaritzky, 2002). Addition of ingredients to reduce the amount of oil uptake in deep-fried foods has been met with varying sensory characteristics. Characteristics desired in fried food include a crunchy, dry crust and golden color (Mah & Brannan, 2009). Foods that do not meet these expectations are considered to be of lower quality and will be of less appeal to consumers. The addition of WPI as an ingredient in fried foods has proved effective at reducing the amount of oil absorbed during frying; however, it can also have an effect on sensory attributes including flavor, texture, and color (Mah & Brannan, 2009).

It has been reported that the addition of HPMC to batter improved the flavor of deep-fried chicken samples (Arc a et al., 2002). Trained panelists observed no significant flavor differences in chicken samples battered, breaded with JBC, and dipped in WPI except for bitterness. Bitterness was perceived to increase with increasing concentrations of WPI; however, the size of the bitterness scores was very small (0.0 to
French fries coated with a combination of 5% pectin and 0.5% calcium chloride produced the most significant reduction in oil content, retention of moisture content, and scored the highest ratings among a sensory analysis panel (Khalil, 1999).

A sensory analysis panel as well as instrumental analysis are two methods used to determine the texture qualities of deep-fried foods (Mah & Brannan, 2009). One concern is that the increased amount moisture retained during frying would reduce the crispiness of the crust (Dragich & Krochta, 2010). Mah and Brannan (2009) found a significant difference in chicken samples coated with crackermeal and dipped in 10% WPI in hardness and crunchiness when compared to a nondipped control. They defined hardness as the force needed to bite through a sample and crunchiness was attributed to the amount of fracture and sound perceived when the sample was chewed once with the molars. Texture differences in JBC coated and WPI dipped patties were not significant compared to a control which was not dipped (Mah & Brannan, 2009).

Color is an important determinant in the quality of fried food. Food that is dark in color is thought to have been fried in degraded oil, cooked for too long, or to possess off flavors (Mah & Brannan, 2009). Protein undergoes browning and therefore the use of WPI, or other proteins, as a batter ingredient or a dip for deep-fried food could have an effect on the overall color of the food. Color analysis can be evaluated by visual appearance (Dragich & Krochta, 2010), a colorimeter, or both. Parameters evaluated include lightness (L*) and chromaticity coordinates a* and b*. L*, a*, and b* values were all lower for chicken samples dipped in WPI at pH 8 than the undipped control as
well as WPI at pH levels of 2 and 3. The samples that were dipped in WPI at pH 8 appeared burned and unattractive (Mah & Brannan, 2009). When dried egg white was used as a postbreading dip for deep-fried chicken samples no significant differences in color parameters were detected (Myers & Brannan, 2012)

![Figure 4. a* and b* chromaticity diagram. +a* is the red direction, -a* is the green direction, +b* is the yellow direction, and –b* is the blue direction (Konica Minolta, 1987). Copyright 1987 by Konica Minolta Inc. Reprinted with permission.](image)

**Conclusion**

Fried foods are popular in the United States and around the world (Barbut, 2013). Fried food contains high amounts of fat; sometimes up to one third of the product by weight. Consumption of fat above the recommended amount of 35% calories from fat can lead to heart disease, stroke, type 2 diabetes, and certain types of cancer (CDC, 2009-
2010a). Consumers interested in decreasing their fat consumption have become attracted to reduced fat products (Lim et al., 2010).

The process of frying involves complicated heat and mass transfer that is affected by many factors (Brannan et al., 2014). Several studies have been conducted in attempt to reduce the amount of oil uptake in fried food. Two popular methods are optimizing frying conditions and the addition of oil inhibiting ingredients. Parameters that have been optimized include fry time, oil temperature, oil composition, and handling of food after frying. Foods fried under these optimized conditions are generally found to have reduced oil absorption (Mellema, 2003). Oil inhibiting ingredients that have been studied include certain proteins and nonprotein hydrocolloids. Researchers attribute the oil inhibition properties of corn, egg, soy, and whey proteins to their ability to form heat-induced gels.

WPI was chosen because it has offered the most promising results in past studies in our research lab. Parameters including protein concentration and pH have been studied and levels were determined at which lipid inhibition was highest (Mah et al., 2008). WPI has proved effective at reducing the oil content of deep-fried chicken samples both as an addition to batter and as a postbreading dip (Dogan et al., 2005; Dragich & Krochta, 2010; Mah et al., 2008). Neither of these methods produced a chicken sample that is 35% of calories from fat or less and, therefore, it would be beneficial to investigate a combination of these applications.
Chapter 3: Methods

Overall Approach

To prepare the chicken samples, a standard breading procedure was used. Raw chicken was dusted with flour, then coated with batter to which WPI was added, breaded, and dipped in a solution of WPI. Undipped samples coated with the batter that contains no WPI served as the negative control. Because previous research has shown a 37.5% lipid reduction in ground chicken samples coated with batter (0% WPI) and dipped in a 10% WPI solution before frying, samples with this combination served as the positive control (Mah et al., 2008). A flowchart of the sampling scheme is shown in Figure 5.

Materials

All chemicals used in the analysis were obtained from Thermo/Fisher (Waltham, MA). All food material including chicken breast, distilled water, Japanese bread crumbs, and batter ingredients were purchased from local retailers. Davisco Foods International (Eden Prairie, MN) donated WPI (biPro®) and Jones-Hamilton Co. (Walbridge, OH), donated food grade sodium bisulfate (pHase®).
Figure 5. Flow chart for methods and procedures.
Preparation of Samples

All natural (i.e., not “enhanced” or with added water) chicken breasts were cut into cubes weighing 10 ± 1g. They were prepared a day ahead and held at 41 °F for less than 24 hours. The standard batter recipe used consisted of 48.75% wheat flour, 48.75% corn flour, 1% xanthan gum, 1% salt, 0.5% baking powder, and deionized water (Sahin, Sumnu, & Altunakar, 2005). Deionized water was added to the dry ingredients until a viscosity of 3000 ± 100 centipoise (cps) was reached. WPI was added to the batter in three levels (0%, 5%, and 10% w/w). The batter was made on the day it was used and held no longer than 12 hours before use. The WPI solution for the postbreading dip was made by dissolving 10% WPI in distilled water. It was lowered to a pH of 2 using sodium bisulfate (pHase®). The solution was made no longer than 24 hours before it was used and stored at 41 °F. Chicken samples were weighed in batches of 5 and then coated with a predust (wheat flour). The excess flour was shaken off. Each batter formulated was used at its natural pH (6) and also at a pH of 2. To adjust the pH of the batter pHase® was used. The samples were then coated with batter and then Japanese bread crumbs. If no dip was used, samples were immediately fried in vegetable for 2 minutes at 375 °F in a deep fryer (4L Dual Deep Fryer/1800W, Farberware® Inc.). If a dip was used, the samples were submerged in the protein dip and then fried immediately according to the conditions above. Each batch of samples were weighed in between each step and the following measurements were calculated: sample weight, batter pickup, breading pickup, whey pickup, total pickup, weight prefrying, weight postfrying, and weight difference (Mah & Brannan, 2009).
**Objective Analysis**

**Moisture analysis.** Moisture content of the chicken samples was determined using a drying oven. Three chicken samples were chosen randomly from each batch of 5 and ground, individually, using a food processor (Cuisinart® Mini-Prep Plus, East Windsor, NJ 08520) until a uniform mixture of chicken and crust was obtained. Each sample of ground chicken sample (1g) was placed in test tube and weighed. The samples were held in a drying oven until a consistent weight was achieved. The samples were weighed again and the moisture was determined using the following equation:

\[
\text{Moisture } \% = \frac{\text{Initial sample weight (g) - Dried sample weight (g)}}{\text{Initial sample weight (g)}} \times 100\%
\]

**Lipid analysis.** The lipid content of the samples was determined using the Folch method (Folch et al., 1957). Chicken samples were ground until a homogenous mixture was achieved, using a food processor. Samples of ground chicken (1 g) were placed in a test tube and lipid was extracted using a solution of chloroform: methanol (2:1 v/v) with successive additions of 10, 5, and 5 mL. The lipid was extracted in between each addition. A 0.5% solution of NaCl was added (7.5 mL) with the first addition of chloroform:methanol to help distinguish between the aqueous layers that form. Solvent was vented off until only the lipid remained. Samples were weighed and the weight of the lipid was determined using the following equation:

\[
\text{Lipid } \% = \frac{\text{Lipid weight (g)}}{\text{Initial sample weight (g)}} \times 100\%
\]
**Texture and color analysis.** Penetrometry was used to analyze the texture of the chicken samples by means of a Ta-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale NY/Stable Micro Systems, Godalming, Surrey UK) controlled by Texture Expert Software. The samples were penetrated using a 70mm knife-blade on a flat platform at a speed of 10mm/s. The knife-blade was set to penetrate 10mm into the sample. This ensured that the knife-blade broke through the crust of the chicken sample as well as the substrate. The sample was positioned so that half of the sample was under the knife-blade to ensure that the sample was penetrated evenly. Force-determination curves were used to produce the texture measurements of hardness, crust fracture force, hardness/crust fracture force ratio, total work, crust work, and resistance (Brannan, 2008). This procedure was performed once each on three chicken samples from each sample set.

Color was determined using a Konica BC-10 Colorimeter (Konica Minolta Sensing Americas Inc., Ramsey N.J. U.S.A.). Values were collected for lightness (L*), a*, and b*.

**Experimental design.** A 2 x 2 x 3 full factorial design was employed. The main effect of WPI dip had two levels (no dip, dip); the main effect of batter pH had two levels (2 & 6); and, the main effect of percent WPI in the batter had 3 levels (0, 5, & 10). Analysis of variance was employed to determine statistical differences between samples at p < 0.05. Duncan’s Multiple Range test was used to separate means. Statistics were performed using SPSS Statistics 17.0 (Chicago, IL) predictive analytics software.
Chapter 4: Results

Replication

This study was replicated 3 times. Some significant differences in lipid, moisture, color and texture were observed between replications; however, there was no discernable pattern that became apparent. Therefore, no obvious or systematic reason exists for excluding any of the replications and all were included in the analysis to account for this variance.

Effects of Prefry Treatments on Coating Pickup

Only the main effect of WPI dip caused significant differences in total pickup and yield (data not shown). Dipped samples had greater total pickup values and lower yield values. This could be due to the fact that much of the dip weight consisted of water and that water was vaporized in the frying process. The mean weights for the raw samples as well as the mean percentages for predust pickup, batter pickup, breading pickup, dip pickup, total pickup, and yield for the three-way interactions between WPI dip, batter pH, and percent WPI in batter in chicken samples are listed in Table 2. Statistical differences ($p < 0.05$) were observed for total pickup and yield. This was due to the differences between dipped and undipped samples.

According to the USDA, the fried chicken samples that were not dipped in the WPI solution can be considered “nuggets” because they have less than 30% total coating pickup. The dipped fried chicken samples would have to be referred to as “fritters,” according to the USDA (2001), because they contain more than 30% pickup by weight.
### Table 2

**Means for the Three-Way Effects of Batter pH, Whey Protein Isolate (WPI) Dip, and Percent WPI in Batter on the Processing Variables of Deep-Fried Chicken Samples**

<table>
<thead>
<tr>
<th>Batter pH</th>
<th>WPI Dip</th>
<th>Percent WPI in Batter</th>
<th>Raw Weight (g)</th>
<th>Predust Pickup (%)</th>
<th>Batter Pickup (%)</th>
<th>Breading Pickup (%)</th>
<th>Dip Pickup (%)</th>
<th>Total Pickup (%)</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Undipped</td>
<td>0</td>
<td>47.0</td>
<td>2.75</td>
<td>13.26</td>
<td>12.22</td>
<td>-</td>
<td>25.94&lt;sup&gt;b,c,d&lt;/sup&gt;</td>
<td>95.20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Undipped</td>
<td>5</td>
<td>49.7</td>
<td>2.61</td>
<td>11.34</td>
<td>12.31</td>
<td>-</td>
<td>24.22&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>91.41&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Undipped</td>
<td>10</td>
<td>49.3</td>
<td>2.70</td>
<td>10.79</td>
<td>10.61</td>
<td>-</td>
<td>22.32&lt;sup&gt;d&lt;/sup&gt;</td>
<td>93.26&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>0</td>
<td>47.0</td>
<td>3.36</td>
<td>14.19</td>
<td>11.92</td>
<td>10.25</td>
<td>34.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>85.14&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>5</td>
<td>49.0</td>
<td>3.26</td>
<td>10.57</td>
<td>10.94</td>
<td>9.40</td>
<td>30.10&lt;sup&gt;a,b,c,d&lt;/sup&gt;</td>
<td>82.74&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>10</td>
<td>52.7</td>
<td>2.45</td>
<td>11.00</td>
<td>11.65</td>
<td>9.59</td>
<td>30.57&lt;sup&gt;a,b,c,d&lt;/sup&gt;</td>
<td>85.47&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>0</td>
<td>50.7</td>
<td>3.13</td>
<td>9.28</td>
<td>12.24</td>
<td>-</td>
<td>22.85&lt;sup&gt;d&lt;/sup&gt;</td>
<td>93.88&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>5</td>
<td>49.3</td>
<td>2.72</td>
<td>10.73</td>
<td>11.95</td>
<td>-</td>
<td>23.51&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>93.28&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>10</td>
<td>50.0</td>
<td>3.25</td>
<td>11.46</td>
<td>12.04</td>
<td>-</td>
<td>24.61&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>93.97&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>0</td>
<td>49.0</td>
<td>2.76</td>
<td>11.80</td>
<td>12.36</td>
<td>12.32</td>
<td>34.12&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>84.43&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>5</td>
<td>49.7</td>
<td>1.99</td>
<td>11.72</td>
<td>12.29</td>
<td>10.11</td>
<td>31.74&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
<td>86.80&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>10</td>
<td>50.0</td>
<td>2.66</td>
<td>11.44</td>
<td>13.04</td>
<td>11.16</td>
<td>33.38&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>86.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Note. Weights and percentages reported are for batches of 5 each samples. Different letters within a column indicate significant difference (p < 0.05). Undipped samples were not dipped in the WPI solution and therefore have no values for “Dip Pickup.”*
Effects of Prefry Treatments on Lipid and Moisture Content

**Negative and positive controls.** Undipped and dipped samples that were coated with batter (0% WPI, pH 6) served as the negative and positive controls (respectively) for this study. Previous research has shown that dipping samples in 10% WPI resulted in a 37.5% lipid reduction compared to the undipped control. These samples contained approximately 42% calories from fat (Mah et al., 2008). In this study the negative control contained 10.42% lipid and 52.37% moisture. The positive control contained 10.34% lipid and 54.67% moisture.

**Lipid and moisture content.** The main effects of batter pH, WPI dip, and percent WPI in the batter for lipid and moisture content of deep-fried chicken samples are shown in Table 3. There was a significant reduction in the lipid content of chicken samples that were dipped in a 10% WPI postbreading dip as opposed to those that were not. A significant difference also was seen in the level of WPI in the batter. Samples that had 10% WPI in the batter were significantly lower in lipid content than samples that had 0% or 5% WPI in the batter. No significant difference in lipid content was observed between the two levels of batter pH without also considering WPI dip or percent of WPI in the batter.
Table 3

Means and Standard Deviations (SD) for the Main Effects of Batter pH, Whey Protein Isolate (WPI) Dip, and Percent WPI in Batter for Lipid and Moisture Content of Deep-Fried Chicken Samples

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Lipid (%) ± SD</th>
<th>Moisture (%) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batter pH</td>
<td>2</td>
<td>10.33 ± 1.28</td>
<td>52.82 ± 2.40</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>10.28 ± 1.10</td>
<td>52.81 ± 2.22</td>
</tr>
<tr>
<td>WPI Dip</td>
<td>Undipped</td>
<td>10.55a ± 1.20</td>
<td>52.29b ± 2.31</td>
</tr>
<tr>
<td></td>
<td>Dipped</td>
<td>10.05b ± 1.13</td>
<td>53.35a ± 2.18</td>
</tr>
<tr>
<td>Percent WPI in Batter</td>
<td>0</td>
<td>10.43a ± 1.23</td>
<td>52.99 ± 2.26</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>10.24a ± 1.22</td>
<td>52.37 ± 2.15</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>9.86b ± 1.05</td>
<td>53.08 ± 2.38</td>
</tr>
</tbody>
</table>

*Note.* Different letters within a main effect for lipid and moisture content indicate significant differences at p < 0.05.

The two-way interaction plots for lipid and moisture are shown in Figure 7. There are significant interactions for both lipid and moisture; however, these differences were only observed at batter pH 2. The lipid and moisture content for the three-way interactions between WPI dip, batter pH, and percent WPI in batter in deep-fried chicken samples are shown in Table 4. As previously mentioned, the main effects analysis showed that there was no significant difference between samples with batter at pH 2 and pH 6, but there was a significant difference between samples that were dipped and undipped (see Table 3). The three-way interactions reveal that the dipped samples with 10% WPI in the batter at pH 2 contained 12% less lipid than the negative control (0% WPI in the batter at pH 6) and 18% less lipid than the undipped samples with 0% WPI in the batter at pH 2. All dipped samples (0, 5, & 10% WPI in batter) at pH 2 were significantly lower in lipid content than the undipped sample with 0% WPI in batter at
pH 2. No differences in lipid content were observed between any of the samples with batter pH 6, including between the positive control and the negative control.

Figure 7. Two-way interaction plots for lipid and moisture. Note. Different letters within a main effect indicate significant differences at $p < 0.05$.

In general, dipped samples contained higher levels of moisture than undipped samples. No significant differences in moisture content were observed between levels of
batter pH or between the negative and positive control. However, three-way interactions revealed the same differences for moisture content that were observed for lipid content. Dipped samples that had 10% WPI in the batter at pH 2 retained 4% more moisture than the negative control (0% WPI in the batter at pH 6) and 4% more moisture than the undipped samples with 0% WPI in the batter at pH 2. Three-way interactions also revealed that adjusting the pH of the batter to pH 2 caused a reduction of lipid compared to the negative control and undipped samples with 0% WPI in the batter at pH 2 in the order of 10% WPI > 5% WPI = 0% WPI.
Table 4

Means and Standard Deviations (SD) of the 3-Way Effects of Batter pH, Whey Protein Isolate (WPI) Dip, and Percent WPI in Batter on the Lipid and Moisture Content of Deep-Fried Chicken Samples

<table>
<thead>
<tr>
<th>Batter pH</th>
<th>WPI Dip</th>
<th>Percent WPI in Batter</th>
<th>Lipid Content (% ± SD)</th>
<th>Moisture Content (% ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Undipped</td>
<td>0</td>
<td>11.25±0.82</td>
<td>52.26b,c±2.41</td>
</tr>
<tr>
<td>2</td>
<td>Undipped</td>
<td>5</td>
<td>10.60ab±1.61</td>
<td>51.63c±2.91</td>
</tr>
<tr>
<td>2</td>
<td>Undipped</td>
<td>10</td>
<td>10.29b,c±1.15</td>
<td>51.70c±0.96</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>0</td>
<td>9.70b,c±1.08</td>
<td>52.66b,c±1.10</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>5</td>
<td>9.81c,d±0.96</td>
<td>53.30a,b,c±1.44</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>10</td>
<td>9.20d±1.21</td>
<td>54.50a±3.10</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>0</td>
<td>10.42b,c±1.68</td>
<td>52.37b,c±2.49</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>5</td>
<td>10.42b,c±1.28</td>
<td>52.23b,c±1.01</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>10</td>
<td>9.96b,c,d±0.72</td>
<td>53.72a,b±2.10</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>0</td>
<td>10.34a,b,c±0.76</td>
<td>54.67a±2.84</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>5</td>
<td>10.06b,c±0.89</td>
<td>52.33b,c±1.52</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>10</td>
<td>9.98b,c,d±0.79</td>
<td>52.41b,c±1.66</td>
</tr>
</tbody>
</table>

Note. Different letters within a column indicate significant difference (p < 0.05).

Effects of Prefry Treatments Color Attributes

The main effects for color attributes of deep-fried chicken samples are listed in Table 5. The main effects analyses reported no significant differences for L*, a*, and b* between levels of batter pH, WPI dip, or percent WPI in the batter.
Table 5

*Means and Standard Deviations (SD) for the Main Effects of Batter pH, Whey Protein Isolate (WPI) Dip, and Percent WPI in Batter for Color Attributes of Deep-Fried Chicken Samples*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>L* ± SD</th>
<th>a* ± SD</th>
<th>b* ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batter pH</td>
<td>2</td>
<td>58.48 ± 5.21</td>
<td>9.51 ± 2.86</td>
<td>34.43 ± 2.92</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>57.79 ± 5.65</td>
<td>10.02 ± 3.54</td>
<td>34.98 ± 3.77</td>
</tr>
<tr>
<td>WPI Dip</td>
<td>Undipped</td>
<td>58.01 ± 5.00</td>
<td>5.00 ± 3.10</td>
<td>9.96 ± 2.67</td>
</tr>
<tr>
<td></td>
<td>Dipped</td>
<td>58.26 ± 5.85</td>
<td>5.85 ± 3.35</td>
<td>9.57 ± 3.88</td>
</tr>
<tr>
<td>Percent WPI in</td>
<td>0</td>
<td>58.98 ± 4.85</td>
<td>9.45 ± 3.36</td>
<td>34.76 ± 3.70</td>
</tr>
<tr>
<td>Batter</td>
<td>5</td>
<td>58.94 ± 5.41</td>
<td>9.49 ± 3.49</td>
<td>34.59 ± 2.28</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>57.83 ± 6.06</td>
<td>9.54 ± 2.89</td>
<td>34.64 ± 3.72</td>
</tr>
</tbody>
</table>

*Note.* Different letters within a main effect for color attributes indicate significant differences at p < 0.05.

Means and standard deviations of the three-way effects of batter pH, whey protein isolate WPI dip, and percent WPI in the batter on the color attributes (L*, a*, and b*) of deep-fried chicken samples are shown in Table 6. The three-way interactions reveal that the negative (undipped) control was 8% lighter (lower L* value) than the dipped sample with 10% WPI in the batter at pH 6. A significant increase in the yellowness (higher b* value) of the dipped sample with 0% WPI in the batter at pH 2 was observed when compared to the undipped sample with 0% WPI in the batter at pH 2.
Table 6

Means and Standard Deviations (SD) of the 3-Way Effects of Batter pH, Whey Protein Isolate (WPI) Dip, and Percent WPI in Batter on the Color Attributes (L*, a*, and b*) of Deep-Fried Chicken Samples

<table>
<thead>
<tr>
<th>Batter pH</th>
<th>WPI Dip</th>
<th>Percent WPI in Batter</th>
<th>L* ± SD</th>
<th>a* ± SD</th>
<th>b* ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Undipped</td>
<td>0</td>
<td>58.78&lt;sup&gt;a,b,c&lt;/sup&gt; ± 5.12</td>
<td>9.70&lt;sup&gt;a,b&lt;/sup&gt; ± 2.94</td>
<td>33.70&lt;sup&gt;b&lt;/sup&gt; ± 2.28</td>
</tr>
<tr>
<td>2</td>
<td>Undipped</td>
<td>5</td>
<td>56.48&lt;sup&gt;b,c&lt;/sup&gt; ± 6.59</td>
<td>11.23&lt;sup&gt;a&lt;/sup&gt; ± 3.48</td>
<td>35.01&lt;sup&gt;a,b&lt;/sup&gt; ± 3.29</td>
</tr>
<tr>
<td>2</td>
<td>Undipped</td>
<td>10</td>
<td>56.61&lt;sup&gt;a,b,c&lt;/sup&gt; ± 5.33</td>
<td>10.00&lt;sup&gt;a,b&lt;/sup&gt; ± 3.36</td>
<td>34.79&lt;sup&gt;a,b&lt;/sup&gt; ± 3.76</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>0</td>
<td>58.69&lt;sup&gt;a,b,c&lt;/sup&gt; ± 7.34</td>
<td>10.70&lt;sup&gt;a,b&lt;/sup&gt; ± 3.87</td>
<td>37.24&lt;sup&gt;a&lt;/sup&gt; ± 2.48</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>5</td>
<td>60.95&lt;sup&gt;a&lt;/sup&gt; ± 4.43</td>
<td>8.30&lt;sup&gt;b&lt;/sup&gt; ± 2.73</td>
<td>34.51&lt;sup&gt;a,b&lt;/sup&gt; ± 4.01</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>10</td>
<td>59.83&lt;sup&gt;a,b,c&lt;/sup&gt; ± 4.49</td>
<td>8.86&lt;sup&gt;b&lt;/sup&gt; ± 2.99</td>
<td>34.08&lt;sup&gt;a,b&lt;/sup&gt; ± 3.00</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>0</td>
<td>60.94&lt;sup&gt;a&lt;/sup&gt; ± 3.15</td>
<td>8.36&lt;sup&gt;b&lt;/sup&gt; ± 3.38</td>
<td>33.45&lt;sup&gt;b&lt;/sup&gt; ± 3.87</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>5</td>
<td>60.61&lt;sup&gt;a,b&lt;/sup&gt; ± 3.39</td>
<td>8.46&lt;sup&gt;b&lt;/sup&gt; ± 2.52</td>
<td>33.88&lt;sup&gt;a,b&lt;/sup&gt; ± 2.28</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>10</td>
<td>58.95&lt;sup&gt;a,b,c&lt;/sup&gt; ± 3.01</td>
<td>9.28&lt;sup&gt;a,b&lt;/sup&gt; ± 2.44</td>
<td>34.18&lt;sup&gt;a,b&lt;/sup&gt; ± 2.23</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>0</td>
<td>57.54&lt;sup&gt;a,b,c&lt;/sup&gt; ± 2.70</td>
<td>9.05&lt;sup&gt;a,b&lt;/sup&gt; ± 3.40</td>
<td>34.65&lt;sup&gt;a,b&lt;/sup&gt; ± 4.90</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>5</td>
<td>57.71&lt;sup&gt;a,b,c&lt;/sup&gt; ± 6.20</td>
<td>9.90&lt;sup&gt;a,b&lt;/sup&gt; ± 4.68</td>
<td>34.96&lt;sup&gt;a,b&lt;/sup&gt; ± 3.82</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>10</td>
<td>55.91&lt;sup&gt;c&lt;/sup&gt; ± 9.65</td>
<td>10.04&lt;sup&gt;a,b&lt;/sup&gt; ± 3.13</td>
<td>35.51&lt;sup&gt;a,b&lt;/sup&gt; ± 5.63</td>
</tr>
</tbody>
</table>

Note. Different letters within a column indicate significant difference (p < 0.05).

Effects of Prefry Treatments Texture Attributes

The means and standard deviations for the main effects of batter pH, whey protein isolate (WPI) dip, and percent WPI in batter for texture attributes of deep-fried chicken samples are listed in Table 7. A significant difference was observed in total work between percentages of WPI in the batter. The highest value for total work was reported for 0% WPI in the batter. Hardness, crust fracture force, and total work were all significantly higher for samples with batter at pH 2 compared to pH 6. No significant differences were reported for hardness, crust fracture force, crust fracture work, or total work between dipped and undipped samples.
Table 7

Means and Standard Deviations (SD) for the Main Effects of Batter pH, Whey Protein Isolate (WPI) Dip, and Percent WPI in Batter for Texture Attributes of Deep-Fried Chicken Samples

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Hardness (kg) ± SD</th>
<th>Crust Fracture Force (kg) ± SD</th>
<th>Crust Fracture Work (kg•s) ± SD</th>
<th>Total Work (kg•s) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batter pH</td>
<td>2</td>
<td>1.063^a ± 0.335</td>
<td>0.335^a ± 0.145</td>
<td>0.477 ± 0.056</td>
<td>0.145^a ± 0.166</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.994^b ± 0.318</td>
<td>0.318^b ± 0.138</td>
<td>0.441 ± 0.050</td>
<td>0.138^b ± 0.179</td>
</tr>
<tr>
<td>WPI Dip</td>
<td>Undipped</td>
<td>1.042 ± 0.327</td>
<td>0.327 ± 0.146</td>
<td>0.439 ± 0.045</td>
<td>0.146 ± 0.179</td>
</tr>
<tr>
<td></td>
<td>Dipped</td>
<td>1.016 ± 0.330</td>
<td>0.330 ± 0.137</td>
<td>0.478 ± 0.059</td>
<td>0.137 ± 0.166</td>
</tr>
<tr>
<td>Percent WPI in Batter</td>
<td>0</td>
<td>1.027 ± 0.253</td>
<td>0.425 ± 0.131</td>
<td>0.089 ± 0.052</td>
<td>0.681^b ± 0.173</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.888 ± 0.344</td>
<td>0.403 ± 0.114</td>
<td>0.074 ± 0.044</td>
<td>0.574^a ± 0.149</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.963 ± 0.256</td>
<td>0.459 ± 0.155</td>
<td>0.083 ± 0.064</td>
<td>0.655^b ± 0.166</td>
</tr>
</tbody>
</table>

Note. Different letters within a main effect for texture attributes indicate significant differences at p < 0.05.
The means and standard deviations of the three-way effects of batter pH, whey protein isolate WPI dip, and percent WPI in the batter on the texture attributes, (hardness, crust fracture force, crust fracture work, and total work) of deep-fried chicken samples are shown in Table 8. The three-way interactions support significant differences found in the main effects analysis for hardness between levels of batter pH. Few significant differences were observed in crust fracture force and total work between levels of batter pH. A significant difference in hardness was observed between the positive and negative control. The negative (undipped) control was 31% harder than positive (dipped) control. A significant difference also was observed in total work between the positive and negative controls. The negative control had a 38% higher total work value than the positive control. Significant differences in crust fracture force and crust fracture work were not observed between treated samples and the positive and negative controls.
Table 8

Means and Standard Deviations (SD) of the 3-Way Effects of Batter pH, Whey Protein Isolate (WPI) Dip, and Percent WPI in Batter on the Texture Attributes of Deep-Fried Chicken Samples

<table>
<thead>
<tr>
<th>Batter pH</th>
<th>WPI Dip</th>
<th>Percent WPI in Batter</th>
<th>Hardness (kg) ± SD</th>
<th>Crust Fracture Force (kg) ± SD</th>
<th>Crust Fracture Work (kg•s) ± SD</th>
<th>Total Work (kg•s) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Undipped</td>
<td>0</td>
<td>1.089\textsuperscript{a,b,c} ± 0.165</td>
<td>0.474\textsuperscript{b} ± 0.111</td>
<td>0.063\textsuperscript{c} ± 0.026</td>
<td>0.812\textsuperscript{a} ± 0.128</td>
</tr>
<tr>
<td>2</td>
<td>Undipped</td>
<td>5</td>
<td>1.076\textsuperscript{a,b,c} ± 0.420</td>
<td>0.425\textsuperscript{b} ± 0.101</td>
<td>0.088\textsuperscript{a,b,c} ± 0.034</td>
<td>0.647\textsuperscript{a,b,c} ± 0.215</td>
</tr>
<tr>
<td>2</td>
<td>Undipped</td>
<td>10</td>
<td>0.840\textsuperscript{c,d} ± 0.122</td>
<td>0.399\textsuperscript{b} ± 0.073</td>
<td>0.058\textsuperscript{c} ± 0.031</td>
<td>0.593\textsuperscript{b,c,d} ± 0.053</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>0</td>
<td>0.982\textsuperscript{a,b,c,d} ± 0.313</td>
<td>0.423\textsuperscript{b} ± 0.110</td>
<td>0.074\textsuperscript{b,c} ± 0.054</td>
<td>0.663\textsuperscript{a,b} ± 0.156</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>5</td>
<td>1.077\textsuperscript{a,b,c} ± 0.345</td>
<td>0.440\textsuperscript{b} ± 0.104</td>
<td>0.068\textsuperscript{b,c} ± 0.042</td>
<td>0.700\textsuperscript{a,b} ± 0.125</td>
</tr>
<tr>
<td>2</td>
<td>Dipped</td>
<td>10</td>
<td>1.240\textsuperscript{a} ± 0.227</td>
<td>0.651\textsuperscript{a} ± 0.155</td>
<td>0.147\textsuperscript{a} ± 0.096</td>
<td>0.804\textsuperscript{a} ± 0.162</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>0</td>
<td>1.208\textsuperscript{a,b} ± 0.235</td>
<td>0.338\textsuperscript{b} ± 0.184</td>
<td>0.087\textsuperscript{a,b,c} ± 0.051</td>
<td>0.771\textsuperscript{a} ± 0.135</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>5</td>
<td>0.690\textsuperscript{d} ± 0.177</td>
<td>0.345\textsuperscript{b} ± 0.130</td>
<td>0.062\textsuperscript{c} ± 0.036</td>
<td>0.471\textsuperscript{d} ± 0.106</td>
</tr>
<tr>
<td>6</td>
<td>Undipped</td>
<td>10</td>
<td>0.870\textsuperscript{c,d} ± 0.199</td>
<td>0.418\textsuperscript{b} ± 0.117</td>
<td>0.075\textsuperscript{b,c} ± 0.041</td>
<td>0.583\textsuperscript{b,c,d} ± 0.136</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>0</td>
<td>0.830\textsuperscript{c,d} ± 0.140</td>
<td>0.465\textsuperscript{b} ± 0.082</td>
<td>0.132\textsuperscript{a,b} ± 0.043</td>
<td>0.479\textsuperscript{c,d} ± 0.069</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>5</td>
<td>0.710\textsuperscript{b} ± 0.222</td>
<td>0.401\textsuperscript{b} ± 0.123</td>
<td>0.079\textsuperscript{b,c} ± 0.066</td>
<td>0.479\textsuperscript{c,d} ± 0.138</td>
</tr>
<tr>
<td>6</td>
<td>Dipped</td>
<td>10</td>
<td>0.902\textsuperscript{b,c,d} ± 0.267</td>
<td>0.368\textsuperscript{b} ± 0.081</td>
<td>0.052\textsuperscript{c} ± 0.019</td>
<td>0.640\textsuperscript{a,b,c,d} ± 0.210</td>
</tr>
</tbody>
</table>

\textit{Note.} Different letters within a column indicate significant difference (p < 0.05).
Chapter 5: Discussion and Conclusion

Effects of Prefry Treatments on Coating Pickup

Significant differences seen in the main effects analysis for total pickup and yield can be attributed to the presence of WPI dip. The dip consists mostly of water which adds significant weight to the samples. It makes sense that the dipped samples have lower yields because the added water on the surface vaporizes during frying, reducing the weight of the finished samples.

Food companies place importance on total coating pickup and yield for economic and marketing reasons. Generally, companies save money when their product yields are higher. This is also true in the case of fried food. Companies must name their products based on government regulated terms which can limit the marketing of food products. The term “fritter” is a common industry term that is often shadowed, to consumers, by an unregulated fanciful name such as “Popcorn Chicken” with the legal name “Chicken Patty ritters” in smaller font underneath. An exhaustive database search did not reveal any literature on consumer perceptions of the term “fritter” compared to “nuggets,” “strips,” or “fingers.” In this study, samples that were dipped in the WPI solution had greater than a 30% pickup and therefore cannot be referred to as “nuggets,” “strips,” or “fingers.” They must be termed “fritters” which can contain up to 65% batter and breading pickup and must be at least 35% meat (USDA, 2001). It is an open question if the designation “fritter” would limit the usefulness of the product, but a strong case can be made for the utility of a product that does not exceed the 35% calories from fat limit. Schools would be able to serve deep-fried chicken samples while meeting the standards
set by the USDA. Reducing the fat content of chicken samples would reduce the total amount of calories consumed, an important factor when attempting to reduce the risk for chronic diseases including heart disease, stroke, certain cancers, diabetes, and obesity (CDC, 2009). If even a small reduction in the fat content of fried foods was achieved, the total number of calories reduced in the American diet would be vast.

Effects of Prefry Treatments on Lipid and Moisture Content

Lipid. In this study, the pH of the batter, naturally around 6, was lowered to pH 2 to determine if controlling for batter pH had an effect on the lipid content of deep-fried chicken samples. When the batter pH is considered as a main effect, i.e., not taking into account the percent of WPI in the batter or if the samples were dipped after breading, no significant reduction in lipid content was achieved. However, the two-way interactions along with the three-way interactions make it clear that adjusting the batter to pH 2 did cause a reduction in lipid in the samples.

β-Lactoglobulin, the main protein in WPI, forms a gel when it is heated in an aqueous solution. The structure, properties, and strength of this gel depend on the protein concentration as well as the ionic strength and pH of the solution (Sagis et al., 2002). Gels that are formed at the isoelectric point of the protein (5.1) contain large and random aggregates. Gels that are formed far from the isoelectric point (i.e., pH 2) form short, linear strand-like aggregates which are even in consistency and transparent (Sagis et al., 2002). Previous research has shown that lowering the pH of an aqueous WPI dip to pH 2 decreased the oil content of deep-fried chicken patties (Mah et al., 2008). These authors speculate that lowering the pH resulted in gel formation that was responsible for
inhibiting oil absorption into the product. Thus, it makes sense that lowering the pH of the batter away from the isoelectric point of WPI could also result in better gel formation when compared to using batter at its natural pH (6) which is closer to its isoelectric point.

Previous studies have shown that WPI both as a postbreading dip and as an ingredient in the batter is effective at reducing the fat content of deep-fried food (Dogan et al., 2005; Dragich & Krochta, 2010; Mah et al., 2008; Marquez, Di Pierro, Esposito, Mariniello, & Porta, 2013). Previously in our lab, deep-fried chicken patties that contained 42% of calories from fat were achieved using a 10% WPI postbreading dip (Mah et al., 2008). In this study, an 18% decrease in fat content was observed between dipped samples with 10% WPI in the batter at pH 2 compared to the undipped samples with 0% WPI in the batter at pH 2. It was unexpected that the samples with batter pH 6 did not exhibit a reduction in lipid as previously reported. In other words, the positive control did not contain significantly less lipid than the negative control. Mah et al. (2008) used ground chicken breast to form the patties that were then coated and fried. This difference in the texture of the substrate could be one reason that they found a lipid reduction between dipped and undipped samples with batter at pH 6 and this study did not.

The study mentioned in the previous paragraph found that increasing the protein concentration, up to 10% protein in solution, caused a decrease in the oil absorption of deep-fried chicken nuggets (Mah et al., 2008). Low concentrations of protein in solution may favor interactions within the protein molecules themselves instead of the molecules interacting with each other, which would lead to gel formation (Belitz & Grosch, 1999).
As the protein concentration increases it is more likely that intramolecular attractions will occur so that the protein can form a gel (Bolder, Vasbinder, Sagis, & van der Linden, 2007). Protein concentrations that are too high can cause the solution to become viscous.

Ensuring that both the batter and the dip were at pH 2, well below pH 5.1 which is the isoelectric point of WPI, could be responsible for the favorable lipid reduction observed in samples to which the batter was adjusted to pH 2. Samples made with the batter containing WPI at pH 6 were surrounded by breading which was saturated with WPI dip at pH 2. Thus, an interface existed with two pH levels on opposite sides of the isoelectric point in contact with one another. This could bring the total pH of the sample coating closer to the isoelectric point of WPI, hindering protein gelation and subsequent oil inhibition.

Since the goal of this study was to produce deep-fried chicken samples that were 35% of calories from fat or less, it is useful to compare the samples with the lowest fat content. This study produced samples that contained 36% calories from fat compared to the higher fat samples which contained 41% calories from fat. While 36% calories from fat is much closer to the goal of 35% calories from fat, the goal was not reached and further research will be needed to meet this goal.

**Moisture.** The moisture content of samples that were dipped in the WPI solution was significantly higher than undipped samples. This can be attributed to the barrier properties of gels formed by WPI (Gosal & Ross-Murphy, 2000). Moisture content has been found to be inversely proportional to the amount of oil absorbed (Mellema, 2003).
WPI has the ability to form a thermal gel which acts as a barrier between the food and the oil (Gosal & Ross-Murphy, 2000). This barrier that inhibits oil from entering the food also prevents moisture from leaving the food (Mellema, 2003). There was no significant difference seen in the moisture content of deep-fried chicken samples between levels of batter pH (2 and 6). However, there was a significant difference in the moisture content of dipped compared to undipped samples between the two levels of batter pH.

It is unknown how differences in moisture affect sensory properties of the samples. Mah, Price, and Brannan (2009) did not find any statistical differences in the moisture release of deep-fried chicken patties dipped in 10% WPI compared to patties that were not dipped in 10% WPI when evaluated by a trained sensory panel.

**Effects of prefry treatments on physical attributes.** The main purpose of this study was to determine the amount of lipid reduction using WPI as an ingredient in deep-fried chicken samples. However, it is also important to analyze the appearance and texture of the chicken samples as these attributes are important in determining the overall quality of the samples.

**Color.** The three-way interactions reveal that the negative (undipped) control was 8% lighter than the dipped sample with 10% WPI in the batter at pH 6. The complex carbohydrates in the breading are hydrolyzed producing reducing sugars which then participate in nonenzymatic browning, i.e., Maillard reactions, or caramelization (Mah & Brannan, 2009). In a previous study, the addition of protein to the batter of fried food has been found to increase Maillard reactions (Dogan et al., 2005). The darker samples could be attributed to the presence of WPI dip and therefore increased Maillard reactions.
A significant increase in the yellowness of the dipped samples with 0% WPI in the batter at pH 2 was observed when compared to the undipped samples with 0% WPI in the batter at pH 2. As Maillard reactions produce a golden brown color their increase in the presence of WPI could also be attributed to the increase in yellowness of the dipped samples vs. the undipped samples.

**Texture.** A crispy outer crust and a moist center are characteristics that have been found desirable in fried food (Mah & Brannan, 2009). Hardness, which is the force required to penetrate the sample 5 mm through the crust (Brannan, 2008), was significantly higher for the positive control compared to the negative control. A previous study found that adding 1% or 3% of WPI to the batter of deep-fried chicken samples significantly increased the hardness of deep-fried chicken samples when compared with samples to which no WPI was added to the batter (Dogan et al., 2005). The WPI gel network that is formed upon heating can be brittle, especially when formed at a low pH (Schokker, Singh, Pinder, & Creamer, 2000).

**Conclusion**

The purpose of this study was to determine the effectiveness of WPI as an ingredient based oil reduction strategy in deep-fried chicken samples. Lipid content was of high importance as the goal of this study was to create a deep-fried chicken sample that contained 35% of calories from fat or less. Using WPI as a postbreading dip and adding 10% WPI to the batter, chicken samples were produced that contained 36% calories from fat. While the goal was not met it brings us much closer to producing fried food which meets the guidelines set by the Institute of Medicine.
This study confirms what previous research has found, that 10% WPI is effective at reducing the fat content of deep-fried chicken sample when used as a postbreading dip, however this study determined that lowering the pH of the batter from 6 to 2 resulted in a greater lipid reduction for dipped samples. Lowering the batter pH away from the isoelectric point (5.1) could cause a more strand-like gel to form, which may be a better lipid barrier than WPI gels formed at its isoelectric point. This effect also could be due to the fact that a batter/breading/dip interface exists with two pH levels on opposite sides of the isoelectric point in contact with one another. This could bring the total pH of the sample coating closer to the isoelectric point of WPI, hindering protein gelation and subsequent oil inhibition. The use of WPI also affected the pickup and yield of the chicken samples as well as the moisture content, color and texture. The WPI dip caused an increase in the total pickup of the samples and a decrease in the yield, which resulted in a change of the status of the fried chicken according to the USDA. The dipped chicken must be called “fritters” instead of “nuggets,” “strips,” or “fingers” which could have implications within the food industry.

The physical attributes of the samples were affected by the use of WPI; however, it is not likely that these differences would manifest as differences in sensory quality. The negative control was lighter in color than the dipped sample with 10% WPI in the batter at pH 6. The undipped sample with 0% WPI in the batter at pH 2 and the negative control were both less yellow than the dipped sample with 0% WPI in the batter at pH 2. Differences in color could be cause by Maillard reactions which are increased in the presence of WPI. Hardness was affected by the change in batter pH. Samples with batter
at pH 2 were harder than samples with batter at pH 6. A significant difference in hardness was also observed between the positive and negative controls.

This thesis moves the body of knowledge closer to producing samples with less than 35% calories from fat. Overall, the findings of this thesis support three conclusions:

- Reducing batter pH to 2 caused inhibition of lipid in the dipped samples.
- Increasing the concentration of WPI in the batter caused increased lipid inhibition.
- A fritter with 36% calories from fat was produced.

**Future Studies**

The results of this study were determined using only instrumental analysis. Sensory analysis should be conducted to determine characteristics, such as mouth-feel and flavor, which cannot be determined via instrumental analysis. These characteristics are important when relating results to the food industry.

This study showed that there is potential to reduce the lipid content of deep-fried chicken samples the addition WPI to the batter. Different batter formulations and percentages of WPI could be tested to optimize this application. Batter pH played an significant role in this study and therefore different batter pH levels in combination with different batter formulas could be tested to optimize lipid reduction. The addition of WPI to the batter could also be tested without a breading step to determine if direct contact with the oil would increase protein gelation and oil barrier properties.

Because this study and others show that an increase in moisture usually corresponds to an increase in lipid content, it would be interesting to study how the initial
moisture content of the chicken would affect the oil absorption. Some chicken is “enhanced” with a brine solution most commonly containing salt and water. Foods with higher initial moisture content generally absorb more fat during frying. Studying the mass balance between moisture and lipid during frying could provide further information regarding reducing the fat content of deep-fried chicken.

Different substrates, including different types of meat and vegetables, could be tested using WPI as a postbreading dip and as a batter ingredient to determine the effectiveness. Some applications show increased performance with different types of substrates. Chicken in itself has variations that could be researched. The difference in fat content of light meat and dark meat could play a role in how much oil is absorbed during frying. The texture of the raw chicken, whole pieces vs. ground meat, could show differences in porosity and therefore oil absorption. Different breading types could also be analyzed.
References


nuggets. *Lwt-Food Science and Technology, 50*(1), 110-119. doi:10.1016/j.lwt.2012.06.014


Journal of the American Dietetic Association, 109(8), 1392-1397.
doi:10.1016/j.jada.2009.05.010


doi:10.1111/josh.12022


Sagis, L. M. C., Veerman, C., Ganzevles, R., Ramaekers, M., Bolder, S. G., & van der Linden, E. (2002). Mesoscopic structure and viscoelastic properties of beta-
lactoglobulin gels at low pH and low ionic strength. *Food Hydrocolloids, 16*(3), 207-213. doi:10.1016/s0268-005x(01)00084-4


