Application of Edible Coatings in Maintaining Crispness of Breaded Fried Foods

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ABSTRACT

Crispness is one of the most desirable textural characteristics of breaded fried foods. Consumers often judge the quality of breaded fried foods based on the perceived crispness of the product. Furthermore, today's consumers are showing increasing concern over fat intake. As a result, there is great interest in being able to enhance the crispness and reduce the fat uptake in breaded fried foods without sacrificing other quality attributes. To achieve these goals, modifications to both frying equipment and product formulation have been explored in this study.

In this study, two edible film coatings, methylcellulose (MC) and whey protein isolate (WPI) were incorporated into the batter and pre-dust to determine their effect on the crispness of breaded fried chicken nuggets held under a heat lamp for varying time intervals. Crispness was evaluated by both objective (ultrasonic non-destructive evaluation system) and subjective methods. An untrained sensory panel was used to obtain subjective measurements of product crispness. Panelists rated product attributes such as crispness, juiciness, oiliness and flavor on a simple intensity scale. Additionally, panelists rated the liking of the products on a nine-point hedonic scale (1=dislike extremely, 9=like extremely). Two pressure sources (nitrogen gas and steam naturally released from the food material) were used to determine their effects on product crispness, texture, pressed juice, moisture content, fat content and color.

Products fried with nitrogen gas as the pressurizing medium produced samples that were comparable to or exceeding the quality of products generated by frying with steam, as it relates to product crispness, texture, pressed juice, moisture content, fat content and color. As related to objective crispness, chicken nuggets fried with nitrogen were significantly crispier ($p<0.05$) than those fried with steam. Coating type and application also had a significant effect on product crispness. Samples coated with MC in the pre-dust were crispier than samples coated with WPI. However, no significant differences were found in product crispness, juiciness, oiliness or flavor, and overall liking among samples tested by the sensory panel.

The results of this study demonstrated that applying an edible film coating to the pre-dust and using nitrogen gas as the pressurizing medium can enhance and maintain the crispness of breaded fried foods.

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CHAPTER 1

INTRODUCTION

Deep fat frying is a thermal processing technique that has been widely used in a number of countries throughout the world. Fried food products generate billions of dollars annually worldwide. Fast-food service restaurants rely heavily upon the frying process for cooking a variety of foods such as French fried potatoes, poultry, meat, seafood and vegetables. Optimization of the deep fat frying process allows for the simplification of the controls and documentation of the process, which yields such benefits as increased frying oil life and decreased oil absorption by the product, decreased product rejection rates through tightened process control specifications, energy conservation and reduced operating costs (Blumenthal, 1991).

The popularity of the frying process can be attributed to the characteristics of the foods that are produced. Frying generates flavorful products that have crispy exteriors with moist and juicy interiors. Moreover, fried foods have enticing aromas and visual appeal due to the golden brown color. The development of the color during frying is a major factor in consumer acceptance of fried products. Color can be controlled by the cooking method and medium, condition of the frying oil, ingredient composition and selection of a supplemental breading (Kulp and Loewe, 1990). Of all the characteristics of breaded fried foods, crispness is perhaps the most desirable.

Crispness is synonymous with freshness—fresh vegetables, fruits and snacks are thought to be best when they are firm and crisp (Vickers, 1988). The desirability of crisp, breaded fried foods is what drives research efforts to not only find ways to quantify this attribute, but also develop techniques to extend the crispness of fried foods. Although crispness is an extremely desirable attribute of fried foods, it is not well defined. No reliable method has been developed to accurately quantify crispness.

In past years, crispness was measured primarily by instrumentation procedures in which Instron universal testing machines were used to run compression, penetration and three-point bend tests. The data obtained from instrumentation measurements do not produce high correlations with sensory analysis. Thus, sensory analysis remains the technique most often used to evaluate crispness. Current research is aimed at finding objective methods to quantify this attribute. The evaluation of ultrasonic parameters has been at the forefront of the research to objectively measure crispness. In a study conducted by Antonova (2001), high correlations between ultrasonic parameters and sensory evaluation were found, suggesting that ultrasonic evaluation can be used to accurately and objectively characterize crispness of breaded fried foods.

Edible coatings have been researched as a possible means of reducing oil uptake and limiting moisture transfer during frying, thus creating products that are more moist and lower in fat. However, limited research has been done to study the effect of edible coatings on crispness. Edible films are biodegradable and composed of natural ingredients such as hydrocolloids, proteins, lipids and composites of the three. Some of the most popular films being researched today include the cellulose derivatives [e.g., methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC)], alginate and soy and wheat protein isolates. The ability of these coatings to limit moisture transfer may enable fried food products to maintain their crispness by inhibiting moisture transfer from within the food material to the crust, and by limiting moisture absorption from the environment into the crust.

One of the most popular fryers being utilized within the food industry is the pressure fryer. Pressure frying has been known to produce more juicy and tender products than open fryers (those exposed to atmospheric pressure). However, the current pressure fryer does have its limitations. The current fryer relies upon the fry load to generate the required pressure. As a result, the use of this type of fryer is limited to situations where large fry loads are desired. The development of a pressure frying system in which the size of the fry load is not the limiting factor in pressure generation would be ideal. It is possible that an inert gas such as nitrogen can be used to supply pressure to the fryer (Innawong, 2001). Pressurizing the frying vessel with nitrogen gas eliminates the need for a large fry load.

Hypothesis

The hypothesis of this research is that incorporating an edible film coating into the batter or pre-dust and frying using nitrogen gas as the pressurizing medium can enhance and maintain the crispness of breaded fried foods.

Objectives

The goal of this research was to investigate the use of edible film coatings and pressure conditions as a means of extending the crispness of breaded fried foods. The specific objectives were as follows:

1. Investigate the possibility of incorporating methylcellulose and whey protein isolate into the pre-dust and the batter to maintain the crispness of breaded fried chicken nuggets held under a heat lamp for varying time intervals.
2. Investigate the use of nitrogen gas as a pressurizing medium to enhance product crispness, texture, pressed juice, moisture and fat content and color.

3. Measure the mechanical properties such as peak force, total energy to peak force, and ultrasonic velocity for breaded fried chicken nuggets.
4. Utilize an untrained sensory panel to assess product crispness, juiciness, oiliness and flavor and to determine overall liking of the samples.

Rationale and Significance

Fried food products generate billions of dollars annually worldwide. The ability to continuously produce breaded fried products that are crisp and low in fat is of great benefit to food companies seeking to distance themselves from their competitors. Consumers often associate the quality of fried foods with the perceived crispness. Furthermore, today's consumers are showing increasing concern over fat intake. The development of a low-fat, crispy breaded fried product will not only satisfy the demand for crispy fried foods, but also address a huge health issue, resulting in large economic gains for the company who is best able to achieve this goal. This study was conducted to reveal the possibilities of using edible film coatings and frying with nitrogen gas to maintain the crispness of breaded fried chicken nuggets.

CHAPTER 2

LITERATURE REVIEW

Deep fat frying is the most commonly used thermal processing method within the food industry. Despite its popularity, the theoretical aspects of the frying process are highly complex and can be difficult to grasp. It is essential to understand the series of phenomena that occur during the deep fat frying of foods in order to continuously produce high quality fried products.

2.1 Frying Process

The actual technology of frying is claimed to have originated and been developed near the Mediterranean area due to the influence of olive oil (Moreira *et al.*, 1999). Fried food products generate billions of dollars. In the United States alone, more than 500,000 commercial restaurants use one million metric tons (MMT) or 2.0 x 10^9 lb. of frying fats and oils annually (Moreira *et al.*, 1999). Frying is such a popular process due to the characteristics of the foods that are produced. Deep fat frying produces foods that are not only flavorful, but have tremendous aesthetic appeal due to the golden brown color.

Frying is a highly complex process where a series of phenomena occur simultaneously throughout the entire process. More specifically, there is simultaneous heat, moisture and oil transfer taking place between the product and the heating medium (frying oil). There is also the formation of a crust layer. To complicate the issue even further, the composition of the oil is steadily changing throughout the process. It is extremely important to have an understanding of what is happening during the frying process such that optimization of the process can be achieved.

There have been several simplified models developed to simulate the frying process, but all are specific to the food material being fried. Not all food material behaves in the same manner upon being fried due to differences in geometry and chemical and physical makeup.

2.2 Frying Mechanism

Deep fat frying is a process in which a food material is cooked through continued contact with hot oil that usually ranges between 180 and 205°C. The frying process involves simultaneous heat and mass transfer. The heat is transferred from the oil into the food material while moisture is transferred from within the food material to the oil. Once moisture evaporates from the interior of the food material, void spaces are created. Oil is then able to occupy the space. An understanding of these phenomena is critical to ensuring that high quality fried products are produced with every fry cycle.

2.2.1 Heat Transfer

There are two basic modes of heat transfer involved in the process of deep-fat frying, and those are convection and conduction. The oil serves as the heating medium. Heat is transferred from the oil to the surface of the product by way of convection. It is then transferred from the surface to the center by conduction. Thermal properties of the food material such as specific heat, thermal conductivity and density affect the rate at which heat is conducted. The magnitudes of these properties change throughout the frying process. The literature that is currently available is nearly devoid of reliable thermal properties data relevant to the frying process (Singh, 1995).

Water is an important factor in convective heat transfer. Water migrates from the central portion of the food material radially outward to the walls and edges to replace that which is lost by dehydration at the surface. As the phase change from liquid water to steam occurs, thermal energy from the frying oil is carried off, which prevents burning caused by excessive dehydration (Blumenthal, 1991). Due to the ability of the water to remove thermal energy from the oil, the temperature of the food material only reaches approximately 100°C even though the oil temperature may be around 180°C. As water escapes from the inner portion of the product and comes into contact with the hot oil, bubbles form and move vigorously throughout the oil, therefore causing turbulence (Innawong, 2001). In general, turbulent conditions promote more rapid heat transfer. The amount of water vapor bubbles decrease with increased frying time due to the decreased amount of remaining moisture within the product.

2.2.2 Moisture Transfer

There is typically a mass loss experienced by the product during the frying process due to constant diffusion of water from within the material core. Moisture is evaporated at the product surface as a result of the partial vapor pressure difference between the product and the frying oil. The rate of moisture transfer is directly related to frying time and oil temperature. According to Mittelman *et al.* (1984), moisture diffusion during the frying of French fries is proportional to the square root of the frying time. The rate of moisture loss significantly decreases with increased frying time. During a study on the drying rate of potato chips, it was shown that a reduction in drying time of 60 seconds occurred when the potatoes were fried at 180°C as opposed to 150°C (Moreira *et al.*, 1999).

Rapid drying is critical for ensuring desirable texture of the final product. However, it is undesirable to have excessive moisture loss as it may result in greater absorption of oil by the product. Sustaining higher moisture content in the final product normally results in products having a low final fat content. As water retention is strongly affected by some food additives, incorporating alginates or cellulose could play a major role in changing the amount of moisture loss and oil uptake (Saguy and Pinthus, 1995).

2.2.3 Oil Transfer

Oil absorption into the product is influenced by oil temperature, frying time and surface moisture content, product surface area and pressure (Innawong, 2001). A linear relationship exists between the surface area and the amount of fat uptake. More specifically, the ratios of product weight to frying oil volume and product surface area to volume are extremely important because they determine the extent to which oil is able to penetrate the food material (Moreira *et al*., 1999). An increase in the surface-to-mass ratio of the product will yield an increase in the amount of oil absorption by the product (Saguy and Pinthus, 1995). Blumenthal (1991) postulates that there are basically three surface-to-volume ratios for foods being fried: (1) foods having an all interior volume with a crispy external surface and no possibility of crust differentiation; example: a food product underneath a breading and battering such as chicken; (2) foods having a significant interior volume with a significant external surface and good crust differentiation; example: French fry; (3) foods having no significant interior volume but a high exterior surface area approximating an all crust and no center product; example: potato chip.

In a study of the modeling of deep fat frying of meatballs, Ateba and Mittal (1994), suggest that foods containing fat undergo two fat transfer periods during the frying process: fat absorption and fat desorption. During the fat absorption period, oil diffuses into the product. The fat desorption period is marked by the migration of fat from the product to the surroundings due to capillary forces in the pores. Foods lacking an initial fat content do not experience the fat desorption period. It has been postulated that fat is able to be absorbed into the product due to the moisture migration from within the product. When the moisture is evaporated from the surface, void spaces are left behind in the product. Fat is then absorbed and fills those void spaces. Another interpretation for the mechanism of oil absorption in fried products proposed that most of the oil enters the product from the adhering oil being pulled into the product when it is removed from the fryer, due to the condensation of steam in the product pores, which produces a vacuum (Moreira *et al.*, 1999). This oil absorption mainly occurs during the post-frying (cooling) period. In a study conducted by Moreira and Barrufet (1998) on tortilla chips, it was found that most of the oil (80%) was absorbed during the post-frying period.

2.2.4 Crust Formation

The formation of a golden brown, crispy layer on the outer surface of the product is perhaps the most recognizable characteristic of fried foods. This layer, known as the crust, is formed within minutes after the product comes into contact with the oil. The crust is formed by both chemical and structural changes in the product. The golden color of the crust can be attributed to Maillard reactions involving chemical changes in the sugar compounds on the product surface. Low water content in combination with high temperatures causes Maillard reactions to occur (Olsson and Skjoeldebrand, 1980).

The crust is a dry layer that acts as a barrier between the inner portion of the food material and the surrounding oil. Due to its dry nature and inability to efficiently conduct heat, the crust becomes heat transfer limiting. Not only does the development of the crust influence heat and mass transfer but has influences on oil uptake as well. Several studies have shown that oil uptake during deep fat frying is localized in the crust. Oil tends to concentrate near edges, corners and broken "slots" (Saguy and Pinthus, 1995). As the crust layer begins to thicken as a result of increased frying time, it no longer permits oil to be passed through.

2.3 Mathematical Modeling of Deep Fat Frying

It is imperative that the complexities of the frying process are fully understood so that mathematical models and simulations of the process can be developed. A mathematical model provides insight into how the deep fat frying process can be optimized. Information about the rate of heat, mass and oil transfer along with the required frying time, temperature and pressure can be gained by the use of mathematical models. Williams and Mittal (1999) developed a mathematical model that incorporated heat, moisture and fat transfer in the food and the film. It was determined that the model can be used to optimize film properties or to predict results of using a particular film with a specific product under different frying conditions. Many assumptions are made in order to generate most models, resulting in oversimplifications of the process. However, the oversimplifications are necessary due to the complexity of the various phenomena involved.

Currently, there is no one generalized model of the frying process that can be used for any food product. There have been various simplified models created but all are specific to the food material being investigated. Attempts have been made to combine heat and mass transfer principles to describe the temperature and moisture content profiles in a product during deep-fat frying, but neither model was able to describe the temperature and moisture profiles inside the product (Moreira *et al.*, 1995a).

In a study conducted by Moreira *et al*. (1995b), an attempt was made to model the simultaneous heat and mass transfer in the frying of tortilla chips. The equations that were produced were solved using the finite difference method. The finite difference method is commonly used in the modeling process. It can be a powerful tool in predicting certain parameters involved in the frying process. However, in most cases, the equations are only valid during certain time periods in the process. For instance, some models may only be good predictors during the first five minutes of frying.

There was an attempt to use mathematical models to predict temperature and mass loss in potato strips. The models were based on empirical equations and also on energy balances and phase diagrams (Moreira *et al.*, 1995b). Neither model was able to describe the temperature and moisture profiles inside the product. Therefore, it is extremely difficult to simulate the frying process with the use of mathematical models. However, as previously stated, some models are highly useful during specified time periods in the frying process.

2.4 Frying Oil

Fats and oils play important functional and sensory roles in fried food products. They are responsible for carrying, enhancing and releasing flavor of other ingredients to develop texture and mouth feel characteristics (Moreira *el al.*, 1999). The frying oil is the single most important factor in determining the final quality of deep-fat fried foods. In the frying process, the oil serves as the heating medium. The oil typically reaches temperatures anywhere between 180°C to greater than 200°C.

Elevated temperatures and repeated usage of the frying oil increases its susceptibility to thermal and oxidative degradation. More specifically, chemical reactions such as hydrolysis, polymerization, oxidation and fission occur. As a result of the various chemical reactions, decomposition products such as free-fatty acids (FFAs), hydro-peroxides, surfactants, hydrocarbons and a host of others are formed. In fact, more than 400 different chemical compounds, including 200 volatile products have been identified in deteriorating frying oil (Moreira *et al.*, 1999). Decomposition products along with frying oil temperature, turnover rate, types of food material, the presence of oxygen and water and the design and maintenance of the frying equipment are all factors that affect the rate of degradation of the frying oil. Chemical and physical changes in the oil can prolong frying time, increase oil absorption by the food material and lower the final nutritive value of the product.

The key elements of good frying oil are a bland flavor, pale color and good oxidative and thermal stability during the frying operation (Baskou and Elmadfa, 1999).

Determining the point where these elements no longer exist is a difficult task. There have been many methods developed to determine when frying oils have deteriorated to the point where flavor, texture and nutritional value of the food have been severely diminished, and in some cases, no longer safe. However, no one satisfactory method for determining oil quality has been developed thus far. Sensory evaluation remains to be the most often used method in determining frying oil quality. The right decision of when to discard frying oil would minimize costs and deleterious effects on the quality of fried products and health (Al-Kahtani, 1991).

2.4.1 Frying Oil and Food Quality

Frying oil is repeatedly used at elevated temperatures in the presence of oxygen and moisture. This results in the accumulation of decomposition products that affect not only food quality, but human health as well. The term decomposition products refer to all degradation products with molecular weights higher than that of triglycerides. Oil is exposed to the action of four agents that cause drastic changes in its structure: (1) moisture from food, giving rise to oxidative alteration; (2) atmospheric oxygen entering oil from the surface of the container, giving rise to oxidative alteration; (3) high temperatures at which the frying operation takes place, which results in thermal alteration and (4) contamination by food ingredients (Moreira *et al.*, 1999). It has been shown that the longer the frying time and the higher the frying temperature, the higher the amount of total polar components (TPC) that will be present in the frying oil. However, if the frying temperature is too low, the food must remain in the oil for a longer period of time in order to fully brown. The extended time in the oil increases oil absorption by the food material. Factors affecting how heated oils and their degradation products interact with food include the food, oil, water-oil interaction, surfactants and oxygen. If there are no changes in processing equipment and no changes in the type or volume of oil in the fryer, then all changes observed in the finished products are due to changes in frying oil (Blumenthal, 1991).

Severely oxidized oils may also have effects on the nutritional value of fried foods. According to Moreira *et al*. (1999), the nutritional value of oils is affected by the loss of polyunsaturated fatty acids, which supplement the essential fatty acid requirement in human metabolism. Furthermore, many of the decomposition products are harmful to human health because they destroy vitamins, inhibit enzymes and can be potential carcinogens.

2.4.2 Changes in Oil during Deep Fat Frying

Blumenthal (1991) researched the quality of French fries fried in oil of varying qualities. He postulated that the oil goes through five phases leading up to degradation, and they are as follows:

1) Break-in-oil: white product; raw; ungelatinized starch at center of the fry; no cooked odors; no crisping of the surface; little oil pickup by food.
2) Fresh oil: slight browning at the edges of the fry; partially cooked (gelatinized) centers; crisping of the surface; slightly more oil absorption.
3) Optimum oil: golden-brown color; crisp, rigid surfaces; delicious potato and oil odors; fully cooked centers (rigid, ringing gel); optimal oil absorption.

4) Degrading oil: darkened and/or spotty surfaces; excess oil pickup; product moving toward limpness; case-hardened surfaces.

5) Runaway oil: dark, case-hardened surfaces; excessively oily product; surfaces collapsing inward; centers not fully cooked; off-odor and –flavors (burned).

The challenge lies in being able to maintain the oil in its optimum state for as long as possible. Attempts have been made to prolong the optimum stage by continuously adding fresh oil to used oil during the frying process. This type of method is effective up until a certain point at which any further addition of fresh oil will have no effect on the overall quality of the oil. The rate at which the oil reaches this point is referred to as the oil turnover rate.

2.4.2.1 Physical Changes in Oils During Deep Fat Frying

The frying oil goes through several physical changes during the frying process and they include an increase in viscosity, change of color, foaming and a reduction in the smoke point. Many of these changes occur as a result of polymerization, in which nonvolatile, high molecular weight compounds are formed. The physical changes that occur are not desirable. When the oil thickens, the rate of heat transfer is reduced. Therefore, it takes longer to cook the food and to produce the desirable golden-brown color. Frying results in darkening of the oil due to oxidation and colored pigments from the food diffusing into the oil (Al-Kahtani, 1991). The smoke point is the temperature at which oil begins to smoke continuously (Moreira *et al*., 1999). Smoking of oil is a direct result of the breakdown of the triglycerides in oil to form FFAs and glycerols. The higher the smoke point, the more suitable the oil is for frying.

2.4.2.2 Chemical Changes in Oils During Deep Fat Frying

Oil undergoes a series of chemical changes throughout the frying process. Many of these changes occur as a result of the presence of moisture being released from the food material and atmospheric oxygen. Atmospheric oxygen reacts with the oil at the surface, thus creating oxidative reactions. Oxidation produces hydroperoxides, which can further undergo three major types of degradation: (1) fission, which produces alcohols, aldehydes, acids and hydrocarbons; (2) dehydration, which produces ketones and (3) free-radical formation, which produces oxidized monomers, oxidative dimmers and polymers, trimers, epoxides, alcohols, hydrocarbons and nonpolar dimmers and polymers (Moreira *et al*., 1999). The frying oil also undergoes other chemical reactions such as hydrolysis and polymerization.

Hydrolysis

Hydrolysis is a chemical reaction that results from the interaction of triglycerides in the oil with water that is released from the food as steam. The interaction between triglycerides and steam form low weight molecular compounds such as free-fatty acids. The rate of FFA formation depend partly on the amount of water in the food, temperature of the oil (higher temperatures created increased FFA production), rate turnover of oil (higher turnover rate, slower production of FFAs) and the accumulation of debris and burnt food particles in the fryer. The debris tends to accelerate the development of FFAs (Boskou and Elmadfa, 1999). Other decomposition products that are produced as a result of hydrolysis include glycerol and mono- and diglycerides.

Polymerization

Polymerization is a chemical process that results in the formation of higher molecular weight compounds called polymers. Polymers and dimers represent degradation products that are unique to fried foods and are excellent chemical markers of oil degradation (Boskou and Elmadfa, 1999). They are nonvolatile decomposition products that are responsible for the physical changes in oil such as increased viscosity, darkened color and foaming. The formation of polymers depends on temperature, surface-to-volume ratio of oil, heating time and fatty acid composition of the oil (Christie *et al.*, 1998).

Surfactants

Interfacial tension (IFT) measures the degree of interaction between the frying oil and the food material. The ability to control the level of IFT can greatly enhance the quality of the frying oil. Chemical compounds known as surfactants make it extremely difficult to control IFT. Surfactants are chemical compounds such as soaps, phospholipids, inorganic salts and polymers that are formed from oxidative reactions in the oil. They act to increase the interaction between oil and water. In a study conducted by Gil and Handel (1995), it was found that the surfactant, sodium oleate, was effective in reducing the IFT in soybean oil used to fry donuts. In fact, sodium oleate reduced IFT to nearly zero at a concentration of just 0.1%. In that same study, soaps were found to have the greatest effect in reducing IFT. Blumenthal (1991) developed a surfactant theory that suggests that controlling surfactant formation is the key to maintaining the quality of the frying oil. Blumenthal's surfactant theory is based on the following assumptions:

1) Frying is basically a dehydration process. When food is fried, water and materials suspended or dissolved in the water are heated and “pumped” from the food to the frying oil.
2) The heat-transfer medium, the frying oil, is a nonaqueous material, whereas the food can be assumed to be almost water. Water and oil are immiscible.
3) For frying to occur, heat must be transferred from the nonaqueous medium---the oil---to the mostly aqueous medium---the food.
4) Any changes in the frying or heat transfer characteristics of the oil must result from degradation products formed from the oil.
5) Food materials leaching into the oil, thermal and hydrolytic breakdown of the oil, and oxygen absorption at the oil-water interface all contribute to altering the oil from a medium that is almost pure triglyceride to a mixture of hundreds of compounds.
6) Substances that affect heat transfer at the oil-food surface reduce the surface tension between the two immiscible materials (water and oil). These substances act as wetting agents and are regarded as surfactants.
7) As the oil degrades, more surfactants are formed, causing increased contact between the food and oil. This causes excessive oil uptake by the food and an increased rate of heat transfer to the surface of the food. Eventually, excessive darkening and drying of the surface occur before the food is cooked, as the rate of conduction of heat to the interior of the food is constant and cannot be accelerated by changes in the oil.

From the surfactant theory, it can be seen that surfactants act as catalysts that enhance many of the breakdown reactions in oil (Gil and Handel, 1995).

2.5 Pressure Frying

In the past thirty years, there has been a significant increase in the variety of deep fat fryers available on the market. In fact, there are more different types of frying equipment than any other heat transfer procedure in food service (Cummings, 1983). The goal of each new design is to provide high quality fried foods while maintaining the quality of the frying oil. An effective automated frying system consists of four requirements: accurate temperature control, efficient heat transfer, minimal oil contamination and oil turnover (Moreira *et al.*, 1999).

The choice of which fryer type to use is critical because the type of fryer greatly influences the quality of the final product. One of the most popular fryers used in the fast food industry is the pressure fryer. This fryer type was initially designed for the frying of chicken. The oil and food capacities range from 11-25 L and 5.6-10.9 kg, respectively. The operating temperatures vary from 160-177°C and frying time from 7-10 minutes (Moreira *et al.*, 1999). In a pressure frying system, a lid covers the fryer so that it is not exposed to the atmosphere. As the food material heats and begins to release moisture in the form of steam, there is a buildup of pressure in the air space above the oil. Once the air space becomes completely saturated with steam, water molecules are no longer able to escape from the food material. This results in a moist, juicy finished product. Although the steam helps to maintain moisture within the product, it also aids in diminishing the quality of the oil. The water creates oxidative reactions in the frying oil, which lead to the formation of undesirable decomposition products.

Frying chicken under pressure is known to yield more juicy and tender product than under atmospheric pressure (Mallikarjunan *et al.*, 1995). In the study conducted by Mallikarjunan *et al.* (1995), it was found that frying chicken nuggets under pressure increased the moisture retention in the samples for both coated and uncoated samples. It is essential to have efficient frying equipment that is capable of meeting the high demands for juicy, crispy deep fat fried foods.

There are many advantages of pressure frying. However, it is limited to the situation where a large fry load is desired. The pressure fryer relies on the steam naturally released from the food to generate adequate pressure within the frying vessel. Innawong (2001) investigated the possibility of using nitrogen gas as the pressurizing medium as opposed to steam released from the food. It was found that nitrogen gas increased moisture retention and the amount of pressed juice in breaded fried chicken. Additionally, frying with nitrogen provided a more tender product than those fried with steam, as measured by a significantly lower energy to peak load and total energy to failure values.

2.6 Batter and Breading of Deep Fat Fried Foods

An array of battered and breaded foods---cheese, fish, meat, poultry, seafood and vegetables represent a fast growing food category in which per capita consumption has risen from less than 5 lb in 1982 to 15 lb during the past ten years (Shukla, 1993). The volume of formulated batters and breadings is estimated at 1.143 billion pounds per year for the U.S. market alone (Ling *et al.*, 1998). The increased popularity of breaded fried foods can be, in part, attributed to their textural characteristics. The breading on a fried piece of chicken enhances the texture, flavor, and appearance of the food. In some products it acts as the major carrier of the seasoning and thus flavor system (Rao and Delaney, 1995). Consumers enjoy the crispy outer layer and the moist and juicy interior. Batters and breadings also contribute to overall flavor by acting as carriers for a variety of seasonings and spices. Batters and breadings can be formulated to reduce oil absorption during frying, control moisture migration within the food material, prevent oxidation of the frying oil and improve nutritive profiles (Shukla, 1993). This fact is important to health-conscious consumers who are often torn between enjoying fried foods and reducing fat intake (Ang, 1993).

The components of the flour affect the characteristics of the batter. More specifically, moisture, protein content and the ratio of amylose to amylopectin have an effect on the crispness of fried batters. Mohammed *et al.* (1998) postulated that the hardness of fried batters is most likely influenced by the degree of polysaccharide-polysaccharide, polysaccharide-water, polysaccharide-oil and polysaccharide-protein interaction. Starches containing higher quantities of amylose typically produce batters with enhanced textural qualities. Increasing the amylose content would increase the polysaccharide-polysaccharide interaction, giving a more crunchy batter and reduced oil absorption (Mohammed *et al.*, 1998).

2.7 Edible Coatings in Frying Process

It has been well documented that edible coatings applied to food substrates before frying aid in limiting moisture and oil transfer during frying (Mallikarjunan *et al.*, 1997; Holownia *et al.*, 2000; Albert and Mittal, 2002; Park and Chinnan, 1995). It is the proven ability of these films and coatings to limit moisture transfer that may be the key to the production of crispier breaded fried products. Furthermore, edible films and coatings, by acting as barriers to control the transfer of moisture, oxygen, carbon dioxide, lipids and flavor compounds, can prevent quality deterioration and increase the shelf life of food products (Mate and Krochta, 1996). As a result, fried foods that are coated with edible films are more moist food products and the films aid in extending the fry life of the oil. Gas and water vapor barrier properties of an edible film and coating vary greatly with composition and presence of bubbles and pinholes of the films (Park and Chinnan, 1995). Edible film coatings are composed of natural ingredients such as hydrocolloids, proteins, lipids and composites of the three. Gums can be applied on a batter-coated food in three ways. The first is as a pre-dust powder directly on the surface of the substrate. The second is a pre-dip solution directly on the surface of the substrate. The third is to use the gum as a coating or to incorporate it into the breading portion by various techniques to improve adhesion and barrier properties. Of these methods, pre-dust applications using gums have been most popular in the industry for improving adhesion, freeze-thaw stability and moisture retention (Kulp and Loewe, 1990).

The chemical and physical structure of edible film coatings is what makes them such effective barriers against oil and moisture. The use of methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC) for their oil and moisture barrier properties has been more widely investigated and reported than use of any of the other hydrocolloids (Kulp and Loewe, 1990). MC and HPMC are cellulose-based hydrocolloids. MC and HPMC exhibit reversible thermal gelation, which causes batters to "set" temporarily during frying. As a result, they reduce batter "blow off" and pillowing and decreases residual debris in cooking oils (Flores *et al.*, 2000). The ability to reduce residual debris in the frying oil is an added advantage of using HPMC and MC in frying. A reduction in batter debris aids in preserving the quality of the fry oil. The removal of debris from the oil is essential because if left unattended, it imparts undesirable flavor and color compounds into the oil, causing it to darken.

Cellulose gums regulate batter viscosity and aids in reducing oil uptake and controlling moisture retention within the food material. In a study conducted by Mallikarjunan *et al.* (1997), it was shown that mashed potato balls coated with MC, HPMC and corn zein (CZ) in comparison to the control, had percent moisture loss reductions that were 31.1, 21.9 and 14.5 for MC, HPMC and CZ, respectively. Percent reductions in fat uptake were 83.6, 61.4 and 59 for MC, HPMC and CZ, respectively. It was also found that among the films tested, MC exhibited the best barrier properties to provide moisture retention and reduction in fat uptake during deep fat frying. The better moisture barrier performance of MC coatings compared to HPMC coatings was attributed to MC being less hydrophilic than HPMC. In a Dow Chemical Co. study (1991), batters formulated with HPMC absorbed 26% less oil than the control after a two-minute fry cycle. Furthermore, an addition of HPMC as a pre-hydrated gum solution to the batter resulted in an even greater oil reduction; up to 50% more in some applications.

Whey protein, a byproduct of the cheese industry, has excellent nutritional and functional properties and the potential to be used for edible films (Mate and Krochta, 1996). When wheat gluten is added to a batter mix, its film-forming properties reduce moisture loss and produce crisp, appetizing surfaces. In a study of the effect of edible coatings on deep-fat fried cereal products, soy protein isolate, whey protein isolate and methylcellulose were found to be the most effective moisture and fat barriers (Albert and Mittal, 2002). Additionally, pre-dusting food with wheat-based films significantly improves adhesion and enhances the appearance (Magnuson, 1985). Whey protein contains lactose, which is a reducing sugar involved in browning reactions that impart more color to the food material (Kulp and Loewe, 1990).

2.8 Quantifying and Evaluating Crispness

Texture is a major factor in determining consumer acceptability of breaded fried foods. Texture can be defined as the sensory manifestation of the structure of the food and the manner in which this structure reacts to the applied forces, the specific senses involved being vision, kinesthetics and hearing. To put it more simply, it is how the food feels in the mouth on manipulation and mastication, and how it handles during transport, preparation and on the plate (Szczesniak, 1990). In past years, studies of texture were pushed into the background in favor of more pressing issues such as adding nutritional value to foods. Now, researchers are paying close attention to the importance of texture and how it influences the purchasing behavior of consumers. Textural characteristics have positive and negative connotations for the consumer. Universally liked textural characteristics are crispness, crunchiness, tenderness, juiciness and firmness (Szczesniak, 1990). It has been shown that in word association tests in which consumers are asked to generate attributes related to a list of specific foods, the term "crisp" was mentioned more often than any other attribute (Roudaut *et al.*, 2002).

Crispness is one of the key textural attributes of interest. Crispness appears to be the most versatile and universally liked single texture. Where crispness occurs, it is the most important attribute and its absence implies poor quality and loss of consumer acceptance (Szczesniak, 1990). Crisp has been defined as hard but easily breakable; brittle and firm and fresh; not soft or wilted (Saklar *et al.*, 1999). A universally accepted definition of crispness has yet to be developed due to the difficulty in understanding exactly what influences the perception of this important attribute. It has been postulated that the loudness of sounds produced when biting a crisp food was very important for quantifying the sensation of crispness, indicating a close relationship between loudness and crispness. Crushing sounds, however, are not the only sensations involved in the perception of crispness. Oral tactile sensations provide much of the information needed for sensory judgments of crispness (Vickers and Christensen, 1980). Different approaches have been reported in the literature on crispness evaluation. The awareness of the importance of texture, coupled with the manufacturers' need to produce a consistent product has led to a need to associate sensory judgment and instrumental measurements (Povey and Harden, 1981).

2.8.1 Instrumental Evaluation of Texture

Knowledge of the sensations of crispness provides the basis for selecting appropriate instrumental measures of the stimuli, whereas useful instrumental measurements provide clues to the nature of the sensations (Vickers, 1987). In the past, textural attributes were evaluated primarily by mechanical testing. Instron machines were used to evaluate parameters such as tensile and yield strength, peak force and energy to peak force. However, these tests have not been effective predictors of texture and overall product quality and consumer acceptability. As a result, research has been focused on developing instrumental tests that are better able to correlate with sensory crispness. Although sensory analysis gives a more complete description of the texture of tested products, there has been great interest in developing instrumental techniques to assess crispness (Roudaut *et al.*, 2002). Instrumental measurements provide a more convenient and cheaper study than sensory evaluation (Pamies *et al.*, 2000). Difficulties in establishing a relationship between instrumental measurements and eating quality may be traced to the single point, nature of the tests. Mechanical properties depend on both strain and rate, but frequently a single strain and rate measurement is made (Du Pont *et al.*, 1992).

Edmister and Vickers (1985) measured crispness by instrumental acoustical measurements. It was found that none of the instrumental acoustical measurements provided a good prediction of oral crispness judgments. Since the oral judgments are the "real" measures of crispness, there was a serious shortcoming in the methodology. Vickers (1987) conducted a study on the sensory, acoustical and mechanical measurements of the crispness of potato chips. In the study, it was found that the single best instrumental measure of oral chip crispness was the number of sounds during biting (r=0.92). The duration of the biting sound was also a good predictor of oral crispness (r=0.87). Additionally, it was concluded that the use of a combination of acoustical and force-deformation measurements can produce an excellent prediction of potato chip crispness.

In a study conducted by Harker *et al.* (2002) on the texture of apples, it was found that measurements of tensile strength were significantly more closely related to sensory assessments of crispness, initial juice release and sustained juice release than any other instrumental measurement. Furthermore, it was shown that comparisons between different instrumental measurements confirmed that puncture tests consistently provided a good prediction of a number of textural attributes of apples. Vickers and Christensen (1980) found that only the instrumental parameters peak force, slope, force-deformation and Young's Modulus showed reasonably high correlations ($r>0.4$) with the three sensory attributes of loudness, crispness and firmness. Of the instrumental measures, Young's Modulus generally correlated most highly with the crispness of all tested foods, while peak force was a better indicator of firmness.

2.8.2 Sensory Evaluation of Crispness

Sensory testing remains the most widely used method to evaluate the level of crispness in foods. Although the sensory approach is the most common, it does have its shortcomings. There may be a certain level of ambiguity associated with the terms used in sensory evaluation. In addition, there is great variability associated with the individuals participating in the sensory testing. Despite these things, sensory is the most reliable method to date used to measure crispness. The pleasure resulting from food consumption is an individual experience, difficult to predict by instrumental measurements. Therefore, the task of assessing the acceptability and preference of products is best carried out by consumers (Bardot *et al.*, 1994). In the past, instrumental measurements have been used to try to quantify crispness. Instrumental measures are best used as a complement to sensory analysis, and can only be seen as reliable if instrumental results are validated against sensory measurements (Rossell, 2001).

In the 1970's and early 1980's, the magnitude estimation method was most often used to evaluate sensory crispness. In this method, one product is chosen as a reference and is given an arbitrary score. The assessors are asked to score the samples proportionally to this reference. In the 1980's, the descriptive analysis became popular and was acknowledged as a reliable technique to measure sensory properties. It became the reference technique for crispness measurement and profoundly changed the experimental protocols (Roudaut *et al.*, 2002). The descriptive analysis technique involves training the panel such that a consensus is reached among the panelists on the meaning of every attribute. A decision has to be made as to which type of panel to use (trained or untrained). The problem with using an untrained panel in descriptive analysis is that there is no guarantee that any two groups, independently trained, would reach the same consensus on the same meaning. In many studies, untrained assessors are used. In this case, a larger number of assessors are needed to compensate the possibility that their concepts were not aligned initially. The question of whether or not untrained assessors are able to quantify their perceptions in a reliable way is still under debate (Roudaut *et al.*, 2002).

There have been relationships found between the sensory and acoustical perception of crispness. In a study conducted by Vickers and Christensen (1980), it was shown that the high correlations and one-to-one relationships between bite only and the bite and chew techniques suggested that the sensory information required to determine food crispness, loudness and firmness is present in the initial bite. Furthermore, it was reported that relationships between the sensory attributes of crispness, loudness and firmness demonstrated that crispness judgments are more highly correlated to the auditory sensation of loudness than to the tactile sensation of firmness.

2.8.3 Ultrasonic Evaluation of Crispness

Ultrasound is simply defined as high frequency sound (>20 kHz). Ultrasound is usually produced by conversion of sinusoidal electromagnetic oscillation, of a single frequency, into ultrasonic waves (Cracknell, 1980). The transmission of an ultrasonic wave through a material depends on the compression and extension of various bonds in the material. Ultrasonic properties are related to the number and strengths of the bonds and hence bulk structure and composition. The compressions and rarefactions are small and the technique is accepted as true non-destructive testing (Saggin and Coupland, 2001). Ultrasonic energy travels through a medium in the form of a wave. Sound waves are produced as a result of the mechanical vibration of particles within a material around their equilibrium points.

Ultrasonics technology was first developed as a means of submarine detection in World War I (Povey and McClements, 1989). Now, ultrasonic measurement has found wide usage in analyzing various properties of food materials. Ultrasonic sensors can be small, robust and resistant to damage from the cleaning and maintenance schedules used in the food industry. These features are ideal for a sensor used in-line in the food factory (Povey, 1989). Low-intensity ultrasound can be used to determine the physicochemical properties of many foods, including composition, structure and physical state (Chanamai and McClements, 1999). Low intensity ultrasonics has major advantages over many other analytical methods because they are non-destructive, rapid, precise, relatively inexpensive, and can be applied to concentrated and optically opaque foods (Llull *et al.*, 2002). The power levels used are low enough to avoid any alteration, either in the physical or chemical properties of the analyzed food.

Antonova *et al.* (2003) investigated the possibility of using a non-destructive ultrasonic technique to quantify crispness of breaded fried chicken nuggets held under different storage conditions and prepared by three different cooking methods (deep-fat frying, oven-baked and microwave). The ultrasonic measurements led to the determination of such ultrasonic parameters as ultrasonic velocity and transmission loss. It was found that samples cooked in a deep-fat fryer had significantly higher ultrasonic velocity (431.56-715.38 m/s) than samples cooked in the oven (221.41-533.83 m/s) and sample cooked in the microwave (90.22-306.92 m/s).

One of the objectives of the above study was to determine how well ultrasonic crispness correlated with sensory crispness. The linear regression technique was used to investigate the relationship between sensory crispness and objective quality parameters of breaded fried chicken nuggets. Increasing sensory crispness of breaded fried chicken nuggets was illustrated by an increase in mean ultrasonic velocity. Therefore, it was concluded that sensory crispness and ultrasonic velocity are closely related and had a high correlation (R^2 =0.83). The following relationship was found:

$$\text{Sensory Crispness} = 0.0127(\text{Velocity}) - 0.6692$$

Antonova *et al.* (2003) concluded that ultrasonic techniques can be used to measure and explain sensory crispness in breaded fried chicken nuggets. The relationship between ultrasonic velocity and sensory crispness suggests that sensory crispness can be reasonably well predicted by ultrasonic velocity.

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CHAPTER 3

THE EFFECT OF PRESSURE CONDITIONS AND COATING TYPE ON QUALITY OF CHICKEN NUGGETS*

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ABSTRACT

Studies have shown that edible film coatings improve the overall quality of fried food products by limiting moisture and oil uptake during frying. The inhibition of mass transfer produces products that contain less fat and retain more moisture, thus creating a juicier lower fat product. Additionally, pressure frying has been known to produce foods that are more juicy and tender than those fried by traditional frying methods. However, pressure frying is limited due to the reliance on the fry load to generate steam required to pressurize the fryer.

The main objective of this study was to determine the effects of two edible film coatings [methylcellulose (MC) and whey protein isolate (WPI)] and two pressure sources (nitrogen gas and steam) on the moisture and fat content, pressed juice and color of breaded fried chicken nuggets. Chicken nuggets were fried in a restaurant-type pressure fryer under a constant pressure of 163 kPa at 175°C for 240 seconds. The fryer was modified such that nitrogen gas could be used to pressurize the frying vessel.

Nitrogen gas produced fried samples that were comparable to or exceeding the quality of those samples fried with steam, as it relates to moisture and fat content, pressed juice and color. Coating type had a significant effect ($p<0.05$) on product moisture and fat content, juiciness and color. The treatment combination of MC incorporated into the pre-dust and frying with nitrogen gas proved to be the most effective at improving the quality characteristics of breaded fried chicken nuggets. The results from this study suggest that using an edible film coating and frying with nitrogen gas can improve the quality characteristics of breaded fried chicken nuggets.

Key Words: edible coatings, pressure frying, nitrogen gas, methylcellulose, whey protein isolate, chicken nuggets

INTRODUCTION

Deep-fat frying represents one of the oldest and most popular thermal processing techniques being utilized today. In the United States alone, more than 500,000 commercial restaurants use one million metric tons (MMT) or 2.0×10^{19} lb. of frying fats and oils annually (Moreira *et al.*, 1999). In providing an effective medium for energy transfer, frying also imparts desirable flavor and textural properties to food (Holownia *et al.,* 2000). Despite its popularity, the theoretical aspects of the frying process are highly complex and difficult to grasp. A series of phenomena occur simultaneously throughout the entire process. More specifically, simultaneous heat, moisture and fat transfer take place between the product and the heating medium (frying oil) and a crust layer is formed on the outer surface of the product. To complicate the issue even further, the composition of the oil steadily changes throughout the process.

Frying under pressure has been shown to produce juicier and more tender products than those produced by traditional frying methods. As a result, one of the most popular fryers used in the fast food industry is the pressure fryer. By appropriately selecting temperature and pressure in deep fat frying, consumer desired characteristics can be obtained in the end product (Innawong, 2001). In a pressure frying system, a lid covers the fryer so that it is not exposed to the atmosphere. As the food material heats and begins to release moisture in the form of steam, pressure builds in the air space above the oil. Once the air space becomes completely saturated with steam, water molecules are no longer able to escape from the food material, resulting in a moist and juicy finished product. The current pressure fryer, however, is limited to situations where a large fry load is desired. Pressure fryers rely on the steam that is naturally released from the food material upon exposure to the hot oil, to generate adequate pressure within the fry vessel.

Many Americans are at high risk for developing heart disease. The excessive consumption of fats and oils increase the risk. The American Heart Association recommends that total fat intake not exceed 30% of the total energy intake, with no more than 8-10% of total energy intake from saturated fats (Wardlaw, 1999). Due to increased concerns over limiting fat intake in the diet, the food industry is faced with the challenge of producing low-fat fried products without compromising taste.

Studies have shown that there is great promise in using edible films to improve the overall quality of fried foods (Ling *et. al.*, 1998; Mallikarjunan *et al.*, 1997; Holownia *et al.*, 2000; Albert and Mittal, 2002; Park and Chinnan, 1995). By suitable selection of edible films it is possible to control moisture and fat transfer between the frying medium and the food (Mallikarjunan *et al.*, 1997). The ability of edible film coatings to inhibit fat transfer may lead to products that are lower in fat. Furthermore, the ability to limit moisture transfer may make it possible for edible coatings to be used to enhance and extend crispness of fried food products. Water holding capacity of food, initial water content and remaining water after frying are all of great importance in controlling texture of both interior and exterior of a fried food (Rossell, 2001).

The primary focus of this study was to determine the effects of methylcellulose (MC) and whey protein isolate (WPI) coupled with two pressure sources (nitrogen gas and steam) on the quality attributes of breaded fried chicken nuggets. The main objective of this study was to characterize moisture retention, fat uptake, pressed juice and color as influenced by the type of edible coating and the source of pressure generation.

MATERIALS AND METHODS

Sample Preparation

Chicken nuggets were obtained from Perdue Farms, Inc. (Bridgewater, VA). The nuggets were pre-dusted, battered, breaded and par-fried at a small pilot plant located within the processing facility. Food grade modified cellulose (E461) was obtained from Dow Chemical Company (Midland, MI). MC and WPI were added to either the pre-dust or the batter (Newlywed Foods Inc., Chicago, IL) before coating the nuggets. The amount of MC and WPI added to the pre-dust was 1% and 3%, respectively. The amount of MC and WPI added to the batter was 3% for each ingredient. The samples were par-fried at approximately 190°C to set the coating. Chicken nuggets were stored in a freezer (-40°C) until needed for the frying experiment.

Frying Experiment

Experiments were conducted using a commercial vegetable oil blend (Bakers & Chefs, North Arkansas Wholesale Company, Inc., Bentonville, AR) as the frying medium. Product samples were taken from the freezer and immediately fried at 175°C and 163 kPa. Two pressure sources, nitrogen gas and steam released from the food, were used to generate the required pressure in a deep-fat fryer (Model 500C, Henney Penney, Inc., Eaton, OH).

The pressure fryer was modified by adding a nitrogen gas flow system developed by Innawong (2001). The exhaust tube which connected the operating valve and the fry pot was replaced by a tee in order to facilitate the flow of nitrogen gas (Figure 3.1). The gas hose from the nitrogen gas tank was connected to the tee which supplied 240 kPa of pressure to the fryer. After the pressure inside the fryer reached a maximum, a safety relief valve connected to the operating valve automatically released the excess pressure to the environment.

Steam released from the food material being fried was the other source of pressure used in this study. In this situation, the amount of pressure supplied to the fryer depends on the amount of the initial fry load. The fry load was kept constant at 1600 g. A typical fry batch included approximately 450 g of tested product and 1150 g of chicken breast patties added as the dummy load. Each of the treatment combinations were fried at the same frying time of 240 s. There was an average 30 s delay in closing and opening the fryer. There were three replications of the frying experiment for each of the treatment combinations.

Samples were held under a heat lamp (Model SW-2430, Merco Inc., Lakewood, NJ) at 60°C for time intervals of 10, 20 and 30 minutes. Some of the samples were analyzed immediately after being taken from the fryer (time t=0).

Color Analysis

The color of the fried samples were measured using a Minolta chromameter (Model CR-300, Minolta Camera, Ltd., Osaka, Japan) calibrated to a white plate (CIE L^* = 97.91, a^* = -0.68, b^* = 2.45, part # 2093326). L^*, a^* and b^* values were used to calculate derived color parameters (Figure 3.2). The test was replicated three times using three different nugget samples.

Product Moisture and Fat Content

The proper method for separation of the surface layer (crust) and core portions was developed with a preliminary test. After careful visual inspection, the crust was removed and the remaining portion was considered to be the core. The mass of the crust and the core were recorded. The moisture content of the crust and the core was determined through the use of a freeze dryer (The Virtis Company, Inc., Gardiner, NY). The freeze dryer used can be seen in Figure 3.3. Freeze drying was chosen over traditional oven drying because freeze-drying removes the moisture without destroying the porous structure of the samples (Innawong, 2001). The fat content of the freeze-dried samples was determined by AOAC method 991.36 (AOAC, 1995) in which a Soxtec extraction unit was used (Figure 3.4). The test was replicated three times.

Pressed Juice

The amount of pressed juiced extracted from the samples was measured using a press method described by Mallikarjunan and Mittal (1994). One gram of sample (core portion) was placed between two sheets of aluminum foil (3.5 × 3.5 cm). The aluminum foil was placed between two sheets of pre-weighed filter paper (Whatman No.5, 110mm diameter). The filter paper was placed between two sheets of plastic wrap. The plastic wrap was used to catch any excess juice. The filter papers were placed between two Plexi-glass plates (12.5 × 12.5 cm). This sandwich was compressed by applying a 20 kPa pressure for one minute. The weight increase of the filter papers was correlated to the expressed juice from the product. The test was replicated three times.

Statistical Analysis

Statistical analyses were performed using the General Linear Model (GLM) program of the SAS software system (SAS, 2000). GLM tested the main effects of pressure source, coating type and coating application on the quality attributes of breaded fried chicken nuggets. In addition, the effects of the treatment interaction between pressure source and coating type on product quality attributes were evaluated. The Least

Square Means method was used to estimate differences among the means of each treatment at the 5% probability level.

RESULTS AND DISCUSSION

The pressure sources, nitrogen gas and steam, had a significant effect ($p<0.05$) on crust moisture content, core fat content and crispness. The treatment interaction of pressure and coating type had a significant effect on color, crust and core moisture content, crust and core fat content, juiciness and product crispness.

Influence of Pressure and Coating Type on Color

The interaction of pressure and coating had a significant ($p<0.05$) effect on the color of the crust. The mean L^* values for samples fried with nitrogen gas and steam were 50.62 and 47.40, respectively. Samples that were fried using nitrogen gas had significantly higher L^* values than those samples that were fried using steam, indicating that the samples fried with nitrogen gas appeared lighter in color (Table 3.1). These are similar to results reported by Innawong (2001) in which it was found that chicken fillet samples fried with nitrogen gas were lighter in color than those samples fried using steam as the pressure source.

Samples coated with MC were significantly different from the control and the WPI-coated samples. The mean L^* values for the control, WPI-coated samples and MC-coated samples were 48.2, 48.8 and 50.0, respectively. Samples coated with WPI were darker than the MC-coated samples, as evidenced by the reduction in L^* and b^* values. Color development in fried products is influenced by starch gelatinization, protein denaturation and non-enzymatic browning of the crust (Sahin, 2000). Whey protein contains lactose, which is a reducing sugar involved in browning reactions that impart more color to the food material (Kulp and Loewe, 1990). WPI-coated samples were not significantly different from the uncoated samples.

Influence of Pressure and Coating Type on Moisture Content

As expected, the moisture content of the core decreased with increased holding time under the heat lamp (Figure 3.5). Once the products were released from the fryer, moisture began to migrate from the crust towards the surface of the product. The crust moisture content also followed a decreasing trend with increased holding time under the heat lamp (Figure 3.5). The decrease in the crust moisture content can be attributed to a slower rate of moisture migration from the core to the surface due to the porous nature of the samples. Since most foods are considered as porous capillary material, the structure of the material determines the ease with which moisture migrates from the inner part of the product to the surface during the frying process (Ateba and Mittal, 1994). Therefore, the rate of moisture evaporation from the surface of the product was greater than the rate of moisture migration from the product center.

Chicken nugget samples fried with nitrogen gas were significantly different from those fried with steam as it relates to crust moisture content. The mean moisture content values for the crust were 32.9% and 31.0% for those samples fried with nitrogen gas and steam, respectively. Samples fried with nitrogen gas produced products with slightly higher crust moisture content.

The pressure-coating interaction had a significant effect on crust and core moisture content (Table 3.2). The mean crust moisture content values using nitrogen gas as the pressure source were 31.1%, 32.9% and 33.8% for the uncoated (control) samples, samples coated with WPI and samples coated with MC, respectively. The MC- and WPI-coated samples were not significantly different. There was not a significant difference between the control samples and those coated with WPI. However, there were significant differences between the control and the MC-coated samples.

Conversely, the mean crust moisture content values using steam as the pressure source were 32.3%, 29.5% and 31.9% for the control samples, MC-coated samples and WPI-coated samples, respectively (Table 3.2). The control was not significantly different from the samples coated with WPI. The control was significantly different from the MC-coated samples. In this case, the crust moisture content of the MC-coated samples was reduced when frying with steam.

The mean core moisture contents of uncoated samples fried with nitrogen and steam were 62.1% and 63.6%, respectively. Products fried with steam had statistically higher core moisture contents than those fried with nitrogen. These results are contradictory to those obtained by Innawong (2001) in which it was reported that chicken samples fried with nitrogen gas had a higher core moisture content than those fried with steam. In the study conducted by Innawong (2001), a dummy load was used with both pressure frying situations (nitrogen and steam). In this study, a dummy load was not used with the fry loads that were pressurized by nitrogen gas. Therefore, additional moisture generation by the dummy load was not seen. The lack of available moisture could possibly account for lower core moisture content in products fried using nitrogen.

The type of coating used did not have a significant effect on core moisture content when frying with either nitrogen gas or steam. Similar results were obtained by Mallikarjunan *et al.* (1997) in which it was found that the type of edible film was not significant with regard to moisture contents of the core region. Moisture removal occurs mainly in the crust and, therefore, the role of the edible film coatings in retaining moisture was limited to the surface.

Influence of Pressure and Coating Type on Fat Content

The mean fat content of the core increased with increasing holding time under the heat lamp (Figure 3.6). The core fat content of samples held under the heat lamp for 0, 10 and 20 minutes were not significantly different from each other. The samples held under the heat lamp for 30 minutes were significantly different from those held at 0, 10 and 20 minutes. The samples that were held under the heat lamp for 30 minutes contained more core fat than those samples held for shorter time periods. An initial interpretation of the mechanism of oil absorption in fried products proposed that most of the oil enters the product from the adhering oil being pulled into the product when it is removed from the fryer, due to the condensation of steam in the product pores, which produces a vacuum (Moreira *et al.*, 1999). Oil absorption mainly occurs during the postfrying (cooling) period. In a study conducted by Moreira and Barrufet (1998) on tortilla chips, it was found that most of the oil (80%) was absorbed during the postfrying period.

Pressure source had a significant effect on core fat content. The mean values for core fat content were 17.4% and 16.7% when frying with nitrogen gas and steam, respectively. Products fried with nitrogen gas had slightly higher core fat content. This result correlates well with the results from the moisture content data in which it was found that chicken nugget samples fried with nitrogen gas had lower core moisture content than those fried with steam. Oil filled the void spaces that were left behind by moisture migration out of the core. It has been postulated that moisture removal and oil absorption are closely related. Saguy and Pinthus (1995) proposed the mechanisms of moisture loss and oil absorption during deep fat frying and they are summarized as follows: (1) high temperature creates "explosive" boiling of the water contained within the fried product, (2) cell walls burst and form capillary holes and voids as a result of the rapid boiling and (3) oil rushes in and fills the holes and void spaces due to water loss and by subsequent cooling, which creates a "vacuum effect."

In the case of using nitrogen gas as the pressure source, no significant differences were found among sample means as it relates to fat content of the crust. When frying with steam, significant differences resulted between MC-coated samples and WPI-coated samples. The mean values for MC-coated samples, WPI-coated samples and the uncoated samples were 23.8%, 25.7% and 24.7%, respectively. The MC-coated samples contained less fat in the crust than the WPI-coated samples (Table 3.2).

Influence of Pressure and Coating Type on Pressed Juice

Pressure source as a main effect did not have a significantly influence the amount of pressed juice produced from the samples. However, the treatment interaction of pressure source and coating type did have a significant effect on the amount of pressed juice (Table 3.1). When comparing WPI-coated samples fried with nitrogen gas and WPI-coated samples fried with steam, it was found that samples fried with nitrogen gas contained more pressed juice. Similarly, products coated with MC and fried with nitrogen gas had a higher mean value for pressed juice, even though they were not significantly different from the MC-coated samples fried with steam.

The type of coating as a main effect had a significant effect on the amount of pressed juice extracted from the product. The mean values for pressed juice were 17.8%, 20.0% and 21.5% for the control samples, WPI-coated samples and MC-coated samples, respectively. The control samples were significantly different from the MC- and WPI-coated samples. The coated samples produced more pressed juice than the uncoated ones. Additionally, there was a significant difference between the two edible coatings. The samples coated with MC were juicier than those coated with WPI.

The type of coating application (pre-dust or batter) did not have a significant affect on the quantity of pressed juice extracted from the samples. The samples in which an edible coating was incorporated into the pre-dust were not significantly different from those samples in which an edible coating was incorporated into the batter.

Even though the results indicated statistical differences in moisture content, fat content and pressed juice, the magnitude of increase in moisture retention, reduction in fat-uptake, or the increase in released juices was very small and did not provide any clear advantage of using one pressure source or coating type over the other. This could be attributed to a threshold pressure above which the benefit of frying under pressure does not provide a meaningful change in the product attributes. Additionally, the lack of variation within the data can also be in large part due to the impact of the dummy load that was used when frying using steam as the pressure source. The lack of a dummy load with the fry batches using nitrogen gas may be the reason for the lower moisture content and subsequent higher fat content in the core region of the samples.

Despite the small variation within the data, frying with nitrogen gas as the pressurizing medium has clear advantages over frying with steam, as indicated by the work done by Innawong (2001). In the study conducted by Innawong (2001), it was shown that frying with nitrogen gas extended the fry-life of the oil. In addition, pressure frying with nitrogen instead of steam directly decreased moisture loss from the fried products and subsequently prevented both thermal and oxidative decompositions of the oil. It was found that the quality of the oil collected from the nitrogen batches after one week were similar to the quality of oil collected from the steam batches after 3-4 days. Furthermore, frying using nitrogen results in a reduction of product waste due to smaller fry loads.

CONCLUSIONS

Statistically, pressure source and coating type did have significant effects on product attributes. Products fried with steam had slightly higher core moisture content than those products fried with nitrogen gas. Coating type had a significant effect ($p<0.05$) on product moisture and fat content, juiciness and color but did not have a significant effect on core moisture content. The color of chicken nuggets coated with WPI was significantly darker than those coated with MC. Additionally, nitrogen gas produced samples that were significantly lighter in color. The treatment combination of MC incorporated into the pre-dust and frying using nitrogen gas proved to be the most effective at improving the quality characteristics of breaded fried chicken nuggets.

Although statistical differences were found among the samples, the magnitude of change in the data was very small and did not provide any clear advantage of using one frying system over the other. The lack of variability in the data could be attributed to the effect of the dummy load. It is suggested that in future studies, the effect of the dummy load on the variability of the data be investigated.

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Table 3.1 Mean pressed juice and color as affected by pressure source and coating type.

Pressure Source[1]	Coating	Pressed Juice (%)	Color		
			L*	a*	b*
steam	Uncoated	20.08 ^{b}	47.56 ^{ab}	13.58 ^{c}	40.69
steam	WPI	17.60 ^{a}	46.20 ^{a}	14.74 ^{d}	40.19
steam	MC	20.88 ^{b}	48.43 ^{b}	12.95 ^{bc}	41.64
nitrogen	Uncoated	15.44 ^{a}	48.82 ^{b}	11.90 ^{ab}	41.12
nitrogen	WPI	22.46 ^{b}	51.41 ^{c}	10.91 ^{a}	41.88
nitrogen	MC	22.11 ^{b}	51.65 ^{c}	11.06 ^{a}	42.41

[1]All samples fried at 163 kPa.
[abc]Means within a column with unlike superscript are significantly different ($p<0.05$).

Table 3.2 Mean moisture and fat content as affected by pressure source and coating type.

Pressure Source[1]	Coating	Moisture (%)		Fat (%)	
		Crust	Core	Crust	Core
steam	Uncoated	32.32 [cd]	63.55 [c]	24.74 [a]	17.11 [bc]
steam	WPI	31.90 [bc]	61.56 [a]	25.69 [b]	17.19 [c]
steam	MC	29.52 [a]	62.39 [ab]	23.79 [a]	16.00 [a]
nitrogen	Uncoated	31.15 [ab]	62.06 [ab]	25.70 [b]	17.82 [cd]
nitrogen	WPI	32.92 [cd]	62.91 [bc]	24.86 [ab]	16.49 [ab]
nitrogen	MC	33.83 [d]	62.07 [ab]	25.33 [b]	18.09 [d]

[1]All samples fried at 163 kPa.
[abcd] Means within a column with unlike superscript are significantly different ($p<0.05$).

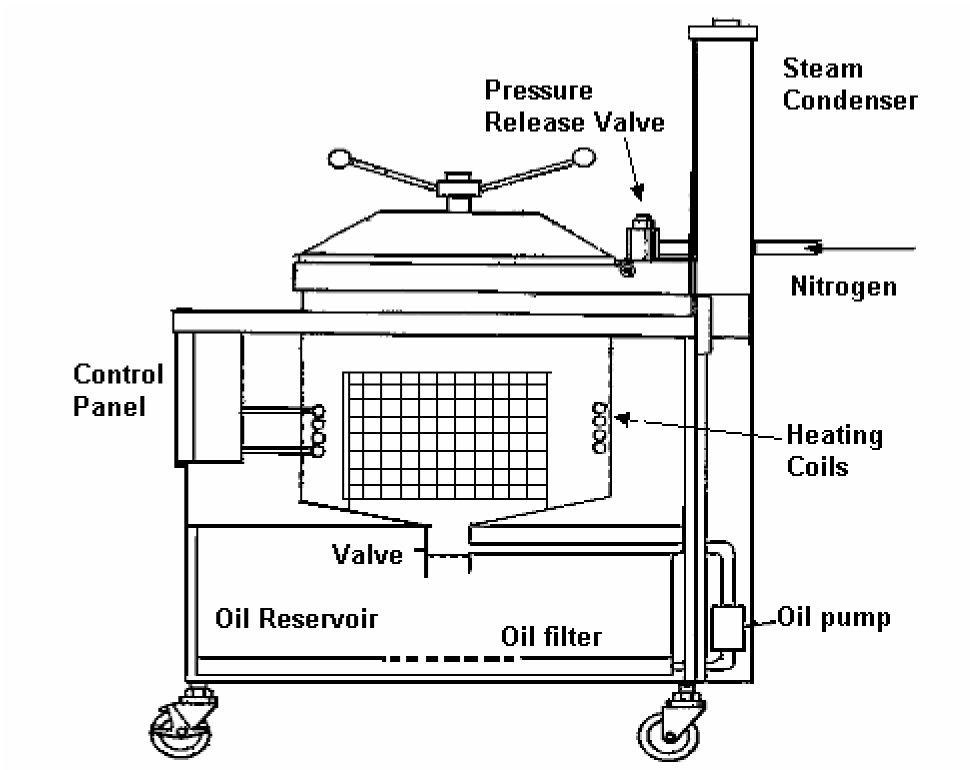
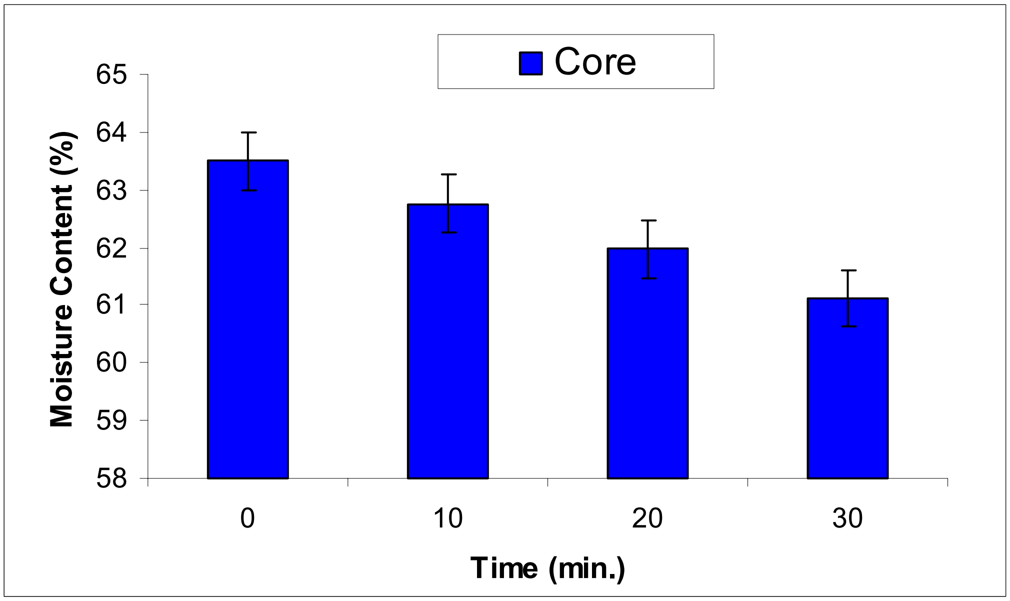


Figure 3.1 Modification of pressure fryer used in this research.

Figure 3.2 Colorimeter used in this study.

Figure 3.3 Freeze dryer used in this study.

Figure 3.4 Soxtec extraction unit used to measure fat content.



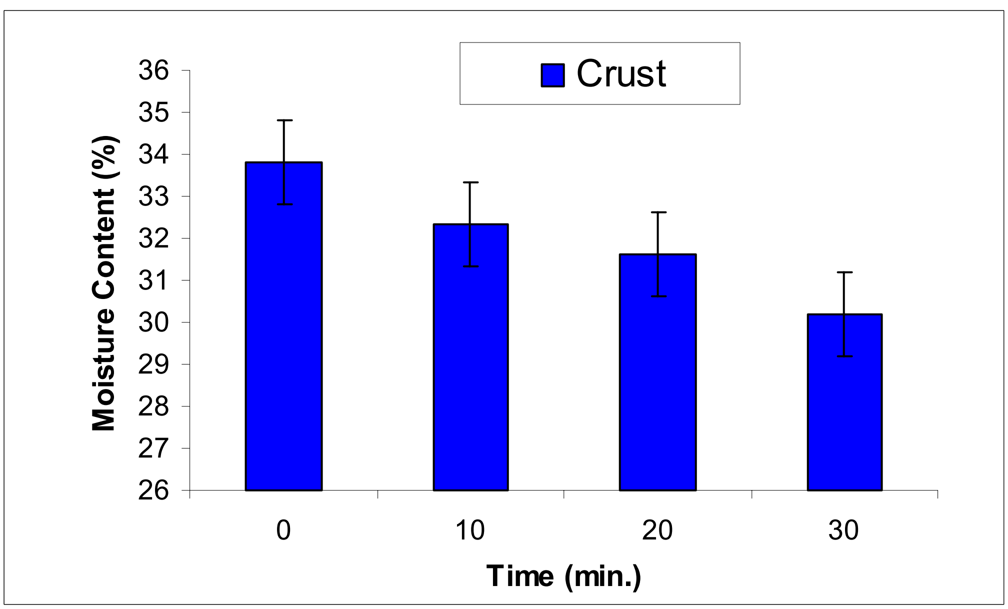


Figure 3.5 Mean moisture content of samples held under a heat lamp (60°C) at different time intervals (0, 10, 20 and 30 minutes).

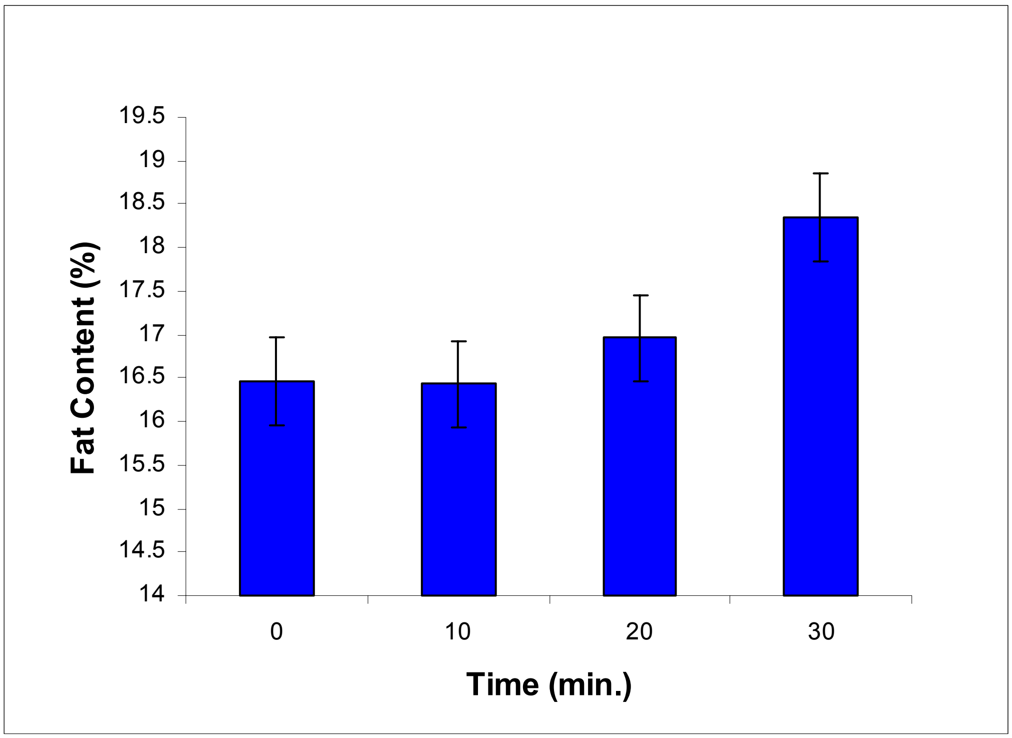


Figure 3.6 Mean core fat content of samples held under a heat lamp (60°C) at different time intervals (0, 10, 20 and 30 minutes).

CHAPTER 4

THE EFFECT OF EDIBLE COATINGS AND PRESSURE CONDITIONS ON CRISPNESS OF CHICKEN NUGGETS*

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ABSTRACT

Crispness is one of the most desirable characteristics of breaded fried foods. Consumers often associate crisp fried foods with high quality. Therefore, there have been increased efforts to develop methods that enhance the crispness of breaded fried foods. Incorporating edible coatings into the breading and batter mixes of breaded fried foods aid in reducing moisture transfer during frying which creates juicier products. The ability to inhibit moisture transfer may be the key to the development of crispier breaded fried products.

Pressure frying may be another key to producing crisp fried products. Frying under pressure increases moisture retention within the core of the food material, which allows less moisture to migrate to the crust. Furthermore, pressure frying produces products that are juicier and more tender than those produced from traditional frying methods. However, frying under pressure has limitations due to the reliance on steam generated from the fry load to create pressure within the fryer.

The primary focus of this study was to find objective means to characterize crispness of breaded fried chicken nuggets. The main objective was to investigate the use of two pressure sources (nitrogen gas and steam) and two edible coatings [methylcellulose (MC) and whey protein isolate (WPI)] as a means of enhancing the crispness of deep-fat fried chicken nuggets. The effects of incorporating MC and WPI to the pre-dust and the batter, on product crispness were evaluated. A non-destructive ultrasonic technique was used to characterize product crispness. An MTS universal testing machine was used to evaluate mechanical measurements such as peak load and energy to peak load.

It was concluded that MC incorporated into the pre-dust significantly ($p<0.05$) increased product crispness. Additionally, the pressure source had a significant effect on crispness of the samples. Chicken nuggets fried with nitrogen gas as the pressurizing medium were crispier than those fried with steam. Products fried with nitrogen gas were more tender as indicated by lower energy to peak load values.

Key Words: edible coatings, nitrogen gas, methylcellulose, whey protein isolate, chicken nuggets, ultrasonic velocity

INTRODUCTION

Crispness is one of the most critical coating characteristics of breaded fried foods. The coating should ideally exhibit a structure that sufficiently resists the initial bite but then disappears with a quick meltaway in the mouth (Kulp and Loewe, 1990). Textural attributes of fried foods are currently not well defined but are high indicators of product quality. The term texture consists of a number of different physical sensations or group of physical characteristics that: (1) arise from the structural elements of the food; (2) are sensed by touching; (3) are related to the deformation, disintegration and flow of food under force; and (4) are measured objectively by functions of mass, time and distance (Moreira *et al.*, 1999). The texture of the breading in a piece of chicken will largely be dependent on the temperature history, pressure during frying and the specific ingredients included, such as type of flour, browning agents, protein content and other functional agents (Rao and Delaney, 1995).

Consumers often judge the quality of fried foods based on the perceived crispness of the product. Crispness is difficult to maintain once the product is removed from the fryer. When breaded fried products are released from the fryer and exposed to the environment, the crust absorbs moisture from the surroundings and moisture migrates from the center of the product to the crust. As a result, the crust becomes soggy and the product is no longer acceptable to the consumer. Edible coatings may be the answer to the problem of maintaining crispness of breaded fried foods. Edible coatings are biodegradable and compose of natural ingredients such as hydrocolloids, lipids, protein and composites of the three. It has been well documented that edible coatings applied to food substrates before frying aid in limiting moisture and oil transfer during frying

(Mallikarjunan *et al.*, 1997; Holownia *et al.*, 2000; Albert and Mittal, 2002; Park and Chinnan, 1995). It is the proven ability of these films and coatings to limit moisture transfer that may be the key to the production of crispier breaded fried products.

The term ultrasound is defined as vibrations of a material medium which are similar to sound waves, but which have frequencies that are too high to be detected by an average human ear. The study and applications of these vibrations are called ultrasonics (Cracknell, 1980). Ultrasonic measurement is becoming a popular method used to analyze various properties of food materials. Ultrasonic testing is non-destructive, fast and easy to perform. Traditional analytical techniques are of limited value because they are time-consuming and destructive, and so there is a strong emphasis on the development of rapid non-destructive techniques. Low-intensity ultrasound can be used to determine the physicochemical properties of many foods, including composition, structure and physical state (Chanamai and McClements, 1999).

Antonova *et al.* (2003) investigated the use of a non-destructive ultrasonic technique to quantify crispness of breaded fried chicken nuggets. It was shown that there is a high correlation between ultrasonic velocity and sensory crispness, which suggested that ultrasonic velocity can be used to predict sensory crispness.

The primary focus of this study is to find objective means of measuring the crispness of breaded fried chicken nuggets. The main objective of this study was to characterize crispness and texture as influenced by the type of edible coating used and the source of pressure generation.

MATERIALS AND METHODS

Sample Preparation

Chicken nuggets were obtained from Perdue Farms, Inc. (Bridgewater, VA). The nuggets were pre-dusted, battered, breaded and par-fried at a small pilot plant located within the processing facility. MC and WPI were added to either the pre-dust or the batter (Newlywed Foods Inc., Chicago, IL) before coating the nuggets. Food grade modified cellulose (E461) was obtained from Dow Chemical Company (Midland, MI). The amount of MC and WPI added to the pre-dust was 1% and 3%, respectively. The amount of MC and WPI added to the batter was 3% for each ingredient. The samples were par-fried at approximately 190°C to set the coating. Chicken nuggets were stored in a freezer (-40°C) until needed for the frying experiment.

Frying Experiment

Experiments were conducted using a commercial vegetable oil blend (Bakers & Chefs, North Arkansas Wholesale Company, Inc., Bentonville, AR) as the frying medium. The product samples were taken out of the freezer and immediately fried at 175°C and 163 kPa. Two pressure sources, nitrogen gas and steam released from the food, were used to generate the required pressure in a deep-fat fryer (Model 500C, Henney Penney, Inc., Eaton, OH).

The pressure fryer was modified by adding a nitrogen gas flow system. The exhaust tube connected which connected the operating valve and the fry pot was replaced by a tee in order to facilitate the flow of nitrogen gas. The gas hose from the nitrogen gas tank was connected to the tee which supplied 240 kPa of pressure to the fryer. After the pressure inside the fryer reached a maximum, a safety relief valve connected to the operating valve automatically released the excess pressure to the environment.

Steam released from the food material being fried was the other source of pressure used in this study. In this situation, the amount of pressure supplied to the fryer depends on the amount of the initial fry load. The fry load was kept constant at 1600 g. A typical fry batch included approximately 450 g of tested product and 1150 g of chicken breast patties added as the dummy load. Each of the treatment combinations were fried at the same frying time of 240 s. There was an average 30 s delay in closing and opening the fryer. There were three replications of the frying experiment for each of the treatment combinations.

Samples were held under a heat lamp (model SW-2430, Merco Inc., Lakewood, NJ) at 60°C for time intervals of 10, 20 and 30 minutes. Some of the samples were analyzed immediately after being taken out of the fryer (time t=0).

Ultrasonic Non-Destructive Testing

The ultrasonic non-destructive evaluation system developed at Virginia Tech (Antonova *et al*., 2003) was used to conduct ultrasonic experiments. The ultrasonic non-destructive evaluation system consisted of an Ultran BP 9400A high power burst pulser, an Ultran BR 640A broadband receiver, a Tektronix 2232 digital storage oscilloscope, a pair of 250 kHz dry-coupling ultrasonic transducers and a microcomputer system for data acquisition and analysis (Fig.4.1). Four hundred volts was sent from the burst pulser to the transducers with a nominal output impedance of 4 ohms. The broadband receiver had a maximum gain of 64 dB and served as a signal amplifier and filter. The transmitted signal was measured and displayed on the oscilloscope screen. A general purpose interface board (GPIB) was installed in a microcomputer which allowed the digital data to be transferred form the oscilloscope to the microcomputer for further analysis.

The system setup was in the through-transmission mode because breaded fried chicken nuggets are highly attenuative. Two 250 kHz transducers were placed on both sides of the chicken samples, one acting as the transmitter and the other one as a receiver. A transducer holding device was used to apply uniform pressure and to ensure precise alignment of the transducers during each ultrasonic measurement. Prior to ultrasonic testing, the thickness of each sample was measured and recorded.

Ultrasonic Velocity

Ultrasonic velocity is defined as the average speed of ultrasound from one side of the sample to the other. The time-of-flight (*TOF*) is the traveling time of the ultrasonic pulse form one side of the sample to the other. The software program, Matlab was used to determine the *TOF*. A program was written into Matlab that used the cross-correlation technique to calculate the *TOF* (Appendix A5). The sample thickness, *TOF* through the sample and the *TOF* of the transducer were used to calculate the propagation velocity of the ultrasonic wave through the sample. The ultrasonic velocity was calculated according to the following equation:

$$\upsilon_{sample} = \frac{l}{TOF - TOF_0}$$

where

υ_{sample}	=	Ultrasonic velocity for breaded fried chicken nugget (m/sec)
l	=	Path length of transmission (m)
TOF	=	Time-of-Flight for sample (ms)
TOF_0	=	Calibrated time-of-flight without sample (ms)

Texture

The texture of the fried samples were measured using a Kramer shear press apparatus attached to a Sintech/MTS universal testing machine (Model 5G, MTS, NC.). The cross-head speed of the apparatus was maintained at 100 mm/min (Figure 4.2). The peak load (N) and total energy to peak load (N·mm) were calculated to characterize the texture of the fried products. The test was replicated three times.

Statistical Analysis

Statistical analyses were performed using the General Linear Model (GLM) program of the SAS software system (SAS, 2000). GLM tested the main effects of pressure source, coating type and coating application on textural attributes of breaded fried chicken nuggets. In addition, the effects of the treatment interaction between pressure source and coating type on textural attributes were evaluated. The Least Square Means method was used to estimate differences among the means of each treatment at the 5% probability level.

RESULTS AND DISCUSSION

Influence of Pressure on Ultrasonic Crispness

Mean ultrasonic velocity values decreased with increased holding time under the heat lamp, indicating a steady decrease in product crispness (Figure 4.3). The samples at time t=0 were significantly different from the samples held under the heat lamp for 10, 20 and 30 minutes. The samples at time t=0 were crispier.

Pressure source as a main effect had a significant effect ($p<0.05$) on product crispness. The mean values for ultrasonic velocity were 485.93 and 353.18 m/s for products fried with nitrogen gas and steam, respectively. These results suggest that samples fried using nitrogen as the pressurizing medium were crispier than samples fried using steam.

Influence of Pressure Source and Coating Type on Ultrasonic Crispness

The treatment interaction of pressure source and coating type had a significant effect on sample crispness. The mean ultrasonic velocity for the control samples fried using nitrogen gas was 530.9 m/s. Once the MC was added to the nuggets, the mean ultrasonic velocity increased from 530.9 to 566 m/s. The exact opposite occurred when WPI was added to the samples. The addition of WPI decreased the mean ultrasonic velocity from 530.9 to 385.6 m/s. MC-coated samples were significantly crispier than WPI-coated samples.

An opposite effect was seen upon evaluating the samples fried using steam as the pressure source. The mean ultrasonic velocity for the MC-coated samples and the control samples decreased when steam was used as the pressure source. In the case of the WPI-coated products fried using steam, the mean ultrasonic velocity was higher than that of MC-coated samples fried using steam. WPI appeared to be more effective at enhancing product crispness when steam was used as opposed to nitrogen gas. These results may be due to some unknown interaction between WPI and nitrogen, which results in a less crisp product when frying using the nitrogen. Perhaps, the pressure sources had different effects on the film-forming properties of WPI. There needs to be a greater investigation into the effects of nitrogen on WPI.

Influence of Pressure and Coating Type on Texture

Pressure source as a main effect had a significant effect on sample texture. The mean values for energy to peak load were 2643 and 2556 N·mm for samples fried with steam and nitrogen gas, respectively (Table 4.2). Product fried with nitrogen gas required less energy to reach the peak load. These results are similar to those found by Innawong (2001) in which it was found that frying chicken nugget samples using nitrogen gas resulted in significantly lower energy to peak force and total energy to failure than products fried with steam.

Coating type as a main effect had a significant effect on the energy to peak load. The energy to peak load increased with increased holding time under the heat lamp (Figure 4.4). This result is to be expected due to the moisture loss that naturally occurs upon being held under the heat lamp. As the product remained under the heat lamp, it became tough and therefore required more energy to reach the peak load. The mean energy to peak load values were 2742, 2457 and 2601 N·mm for the uncoated samples, WPI-coated samples and MC-coated samples, respectively (Table 4.2). The control samples were significantly different from both the WPI- and MC-coated samples. The control required the most energy to reach the peak load. The MC-coated samples were significantly different from the WPI-coated samples. The WPI-coated samples had a lower mean energy to peak load value. However, the magnitude of difference was small.

The interaction of pressure source and coating type had a significant effect on peak load (Table 4.3). The control with nitrogen had the highest mean peak load value but was not significantly different from the samples coated with WPI and fried with steam. The mean peak load values for samples fried with nitrogen gas were 516, 419 and 489 N for control samples, WPI-coated samples and MC-coated samples, respectively. Once a coating was added to the nuggets, the peak load significantly decreased for samples fried with nitrogen gas. Opposing results were found upon evaluating the samples fried with steam. In the case of steam, once the samples were coated with WPI, the peak load significantly increased while the samples coated with MC experienced a decrease in peak load value.

Influence of Coating Application on Ultrasonic Crispness

Coating application as a main effect had a significant effect on sample crispness. The mean ultrasonic velocity values for the control, samples in which the edible coating was added into the pre-dust and samples in which the coating was added to the batter were 436.8, 472.3 and 357.2 m/s, respectively. The control samples were not significantly different from the samples in which the edible coating was incorporated into the pre-dust and the batter. However, the samples in which the edible coating was added to the pre-dust were significantly different from the samples in which the coating was added to the batter. Incorporating the coating into the batter decreased the crispness of the samples. Coating application did not have a significant effect on peak load and energy to peak load.

CONCLUSIONS

The treatment interaction of pressure source and coating type had a significant effect on product crispness and texture. Using nitrogen gas as the pressure source generated products that were significantly crispier than products fried using steam as the pressure source. Samples fried using nitrogen gas had lower energy to peak load values, indicating that they were more tender than products fried with steam. MC-coated samples were significantly crispier than those coated with WPI. Furthermore, MC-coated samples were more tender and evidenced by a lower energy to peak load value. The samples in which MC was incorporated in the pre-dust and fried with nitrogen gas were the most crisp and tender.

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Table 4.1 Mean ultrasonic velocity as affected by pressure source and coating type.

Pressure Source[1]	Coating	Ultrasonic Velocity (m/s)
steam	Uncoated	342.64 [ab]
steam	WPI	528.00 [c]
steam	MC	183.69 [a]
nitrogen	Uncoated	530.90 [bc]
nitrogen	WPI	385.63 [b]
nitrogen	MC	565.97 [c]

[1]All samples fried at 163 kPa.
[abc]Means within a column with unlike superscript are significantly different ($p<0.05$).

Table 4.2 Mean energy to peak load for different frying parameters.

Effect of pressure

Pressure Source[1]	Energy to Peak Load (N·mm)
steam	2643 [b]
nitrogen gas	2556 [a]

Effect of coating

Coating	Energy to Peak Load (N·mm)
Uncoated	2742 [c]
WPI	2457 [a]
MC	2601 [b]

[1]All samples fried at 163 kPa.
[abc]Means within a column with unlike superscript are significantly different ($p<0.05$).

Table 4.3 Mean peak load as affected by pressure source and coating type.

Pressure Source[1]	Coating	Peak Load (N)
steam	Uncoated	477 [bc]
steam	WPI	515 [d]
steam	MC	461 [b]
nitrogen	Uncoated	516 [d]
nitrogen	WPI	419 [a]
nitrogen	MC	489 [c]

[1]All samples fried at 163 kPa.
[abcd]Means within a column with unlike superscript are significantly different ($p<0.05$).

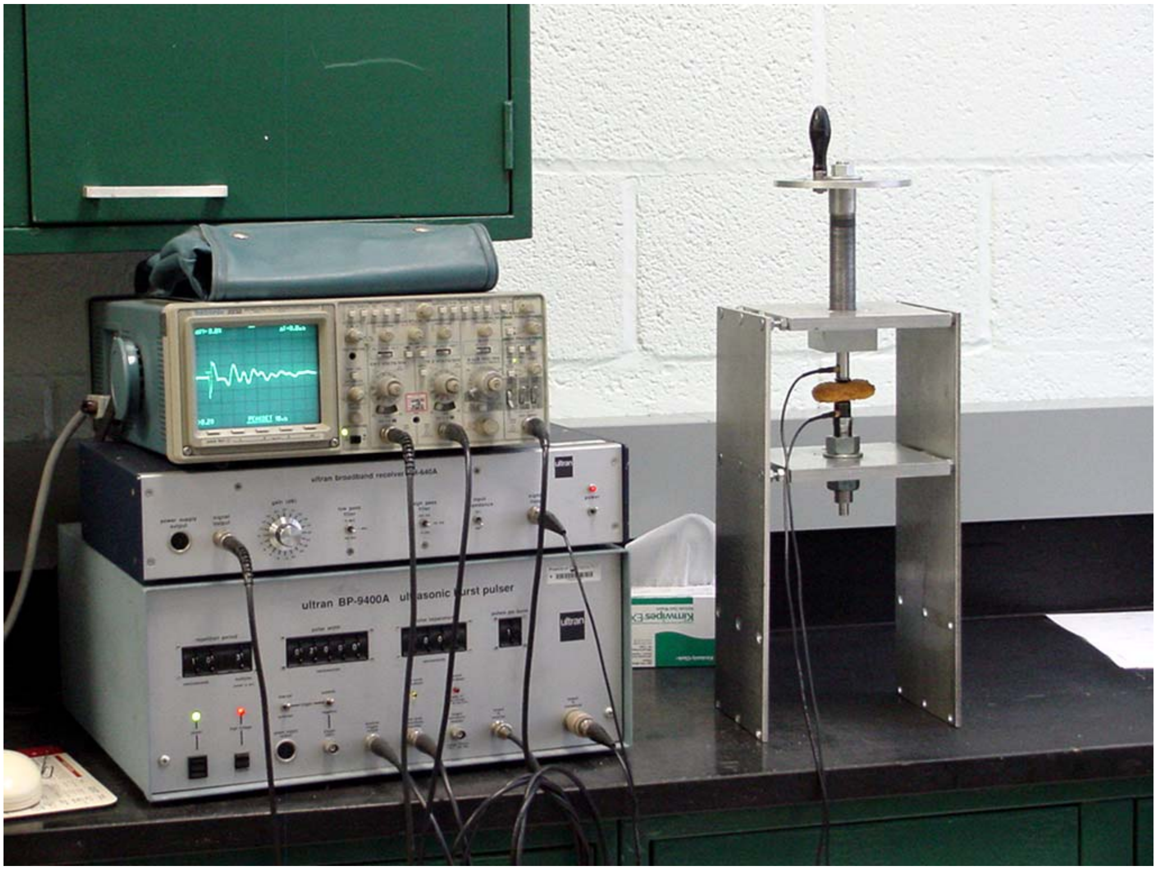

Figure 4.1 Instrumentation setup for 250 kHz ultrasonic transducers in through-transmission mode.

Figure 4.2 Sintech/MTS universal testing machine with Kramer shear press apparatus.

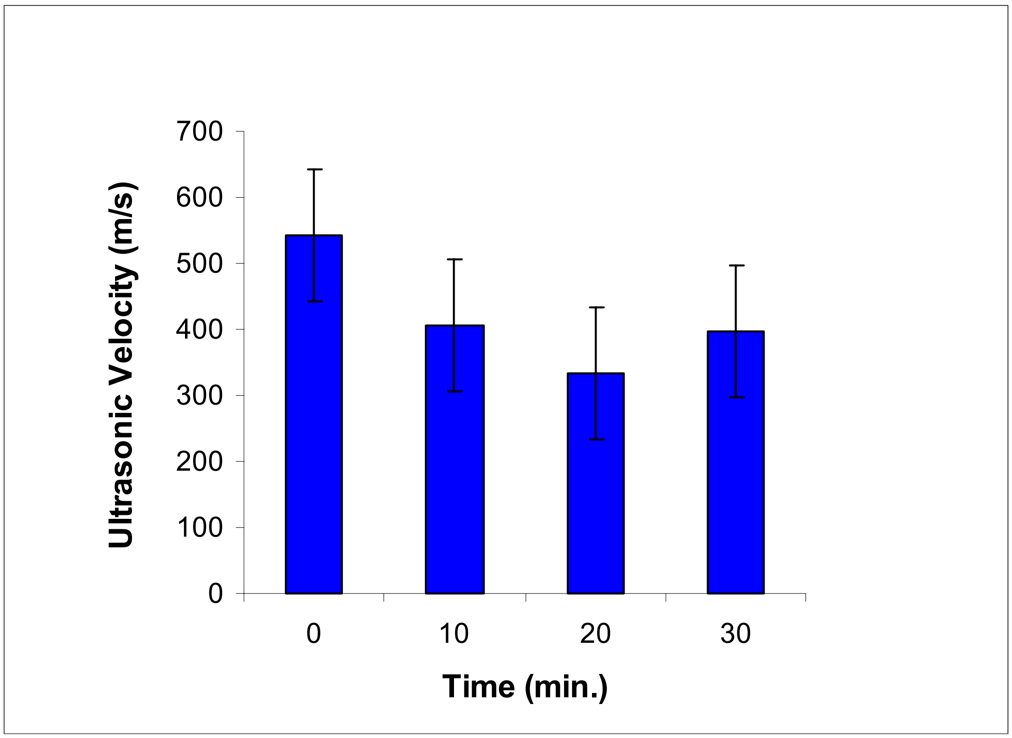

Figure 4.3 Mean ultrasonic velocity for samples held under a heat lamp (60°C) at different time intervals (0, 10, 20 and 30 minutes).

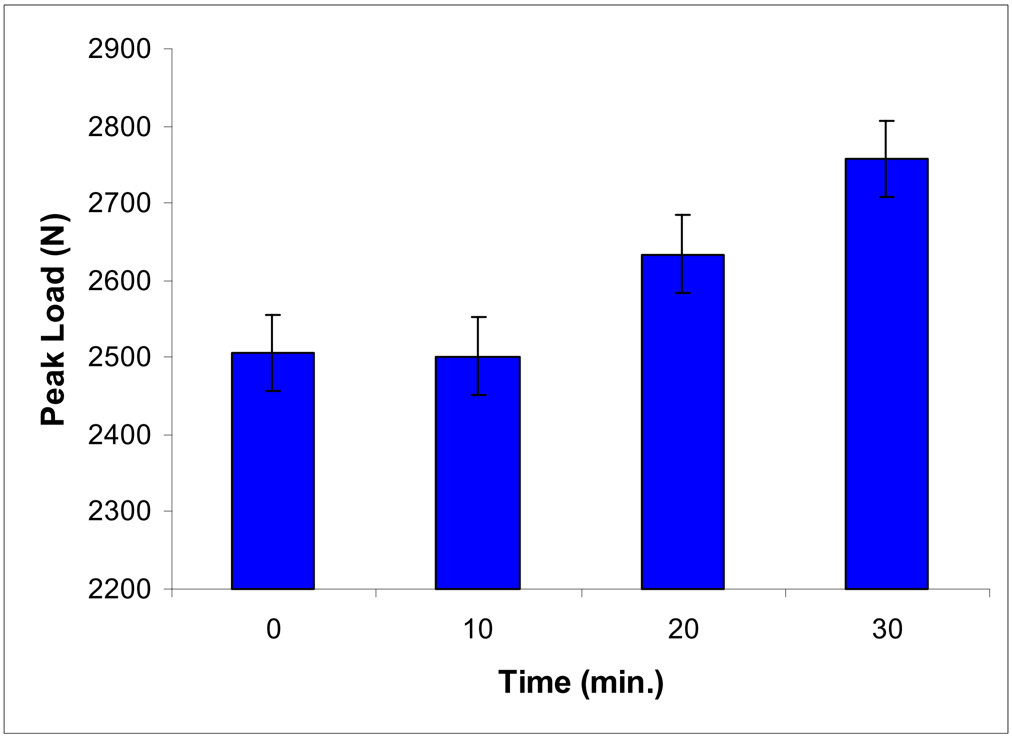

Figure 4.4 Mean peak load of samples held under a heat lamp (60°C) at different time intervals (0, 10, 20 and 30 minutes).

CHAPTER 5

CONSUMER ASSESSMENT OF CRISPNESS OF PRESSURE FRIED CHICKEN NUGGETS USING NITROGEN GAS[+]

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ABSTRACT

Forty untrained subjects were used to determine if sensory differences exist between breaded chicken nugget samples fried with varying treatment combinations. The three treatment combinations used were: (1) samples coated with 3% methylcellulose (MC) incorporated into the pre-dust and fried with nitrogen gas; (2) uncoated samples fried with steam and (3) uncoated samples fried with nitrogen gas. Chicken nuggets were fried in a restaurant-type pressure fryer at 163 kPa and 175°C for 240 seconds. All product samples were held under a heat lamp (60°C) for 15 minutes prior to evaluation by the sensory panelists.

A simple intensity scale and a nine-point hedonic scale were used to determine sample differences and overall liking of the product. The product attributes that were evaluated include crispness, juiciness, oiliness and flavor. It was concluded that at the 5% error level (α=0.05), there were no significant differences in the overall sample means as it related to crispness, juiciness, oiliness and flavor among the three tested samples. The mean overall liking ratings ranged from 5.84-7.32, indicating that in general, the products were well-liked. However, statistically it was shown that no one sample was more well-liked than the other. Although no statistical differences were found among the samples, panelists were willing to pay extra money for samples fried using nitrogen gas.

Key Words: chicken nuggets, methylcellulose, nitrogen gas, simple intensity scale, nine-point hedonic scale

INTRODUCTION

Crispness is one of the most desirable textural characteristics of breaded fried foods. Consumers will praise or condemn a battered or breaded food based on several general factors: appearance, color, crispness, adhesion and flavor (Kulp and Loewe, 1990). The desirability of crisp foods increases the need to develop objective methods to measure this important attribute. Several methods have been found to be somewhat useful in evaluating crispness. However, there remains no one method that can accurately and objectively quantify this attribute.

For some time, instrumental procedures were used to evaluate the texture of various food materials. Instrumental measurements are cheaper and more convenient than sensory evaluation (Dacremont, *et al.*, 2000). Despite the popularity of instrumental procedures for measuring textural attributes such as crispness, data obtained from these procedures do not serve as effective predictors of consumer acceptance, i.e., there has not been good correlation between instrumental and sensory data. In a study conducted by Vickers (1988), an Instron machine was used to crush samples of several dry, crisp foods altered in crispness by humidification. It was concluded that there were large negative correlations between crispness and maximum force at failure and work done to failure. As a result of the inability to predict product crispness from instrumental measurements, sensory evaluation remains the most effective means of evaluating product crispness. The pleasure resulting from food consumption is an individual experience, difficult to predict by instrumental measurements. Thus, the task of assessing the acceptability and preference of products is best carried out by consumers (Bardot *et al.*, 1994).

An affective test such as the nine-point hedonic scale is most often used to evaluate consumer preference and acceptance. The hedonic scale has seen wide usage due to its level of balance, i.e., there are an equal number of positive and negative intervals in the scale. However, the idiosyncratic nature of each judge's internal scale means that it is not an absolute scale. Therefore, the data can only be used comparatively (Gulli *et al.*, 1991).

Antonova *et al.* (2003) investigated the possibility of using a non-destructive ultrasonic technique to quantify crispness of breaded fried chicken nuggets held under different storage conditions and prepared by three different cooking methods (deep-fat frying, oven-baked and microwave). One of the objectives of the study was to determine how well ultrasonic crispness correlated with sensory crispness. Increasing sensory crispness of breaded fried chicken nuggets was illustrated by an increase in mean ultrasonic velocity. Therefore, it was concluded that sensory crispness of samples and ultrasonic velocity were closely related and had a high correlation (R^2 =0.83).

In the sensory study conducted by Antonova *et al.* (2003), a trained sensory panel was used to evaluate sample crispness. The use of an untrained panel of consumers is the true measure of determining how crisp a product is perceived to be. The untrained panelist is a more accurate representation of the typical consumer, who in general, does not have the knowledge to critically evaluate a product based on a specific attribute.

A nitrogen gas flow system was developed by Innawong (2001) to investigate the effects of frying using nitrogen gas on the quality attributes (moisture content, fat content, pressed juice, color and texture) of breaded fried foods. It was found that samples fried using nitrogen gas were comparable to or in some cases, exceeded the quality of those samples fried using steam as the pressure source. Similar results were reported by Ballard *et al*. (2003) in which it was reported that samples fried using nitrogen gas produced products that were significantly ($p<0.05$) crispier than samples fried using steam. It was also reported by Innawong (2001) that nitrogen gas significantly increased the fry-life of the oil. The quality of the oil collected from the nitrogen batches after one week were similar to the quality of oil collected from the steam batch after 3-4 days. Although the above study showed promising results of implementing a nitrogen gas flow system to the current pressure fryer, the effects of frying using nitrogen gas on the sensory quality attributes were not evaluated.

The objective of this study was to expound upon the work done by Antonova *et al.* (2003), Ballard *et al*. (2003) and Innawong (2001) by using an untrained sensory panel to determine if sensory differences exist among chicken nugget samples fried using two pressure sources (nitrogen gas and steam). Additionally, the overall liking and preference of the products were to be determined.

MATERIALS AND METHODS

Tests

Two sensory tests were performed in order to evaluate product attributes and overall liking of the samples. A simple intensity scale was used to evaluate product crispness, juiciness, oiliness and flavor. The anchors of the simple intensity scale were Not crisp/soggy to Very crisp (using crispness as an example). A rating of one was assigned to samples that were perceived as being not crisp/soggy and rating of nine was assigned to the samples that were perceived as being very crisp. A nine-point hedonic scale was used to evaluate the preference or overall liking of the samples. The ratings for the nine-point hedonic scale ranged from 1=dislike extremely to 9=like extremely. The tests were conducted on two separate days.

Panel

The sensory panel for both the attribute intensity test and the hedonic test consisted of 40 untrained faculty, staff and students from Virginia Polytechnic Institute & State University. Panelists were informed of the objectives of the study and given instructions for evaluating samples. They were required to sign a consent form and to provide demographic information prior to participating in the sensory evaluation. Upon completion of the testing, panelists were given a small token of appreciation for participating in the study.

Test Area

The testing took place in a sensory laboratory located on the campus of Virginia Tech. The testing area consisted of eight sensory booths and red lighting was used to mask the differences in color among the samples to be evaluated. The tests were conducted during the hours of 10 am to 3:30 pm.

Sample Description

Chicken nuggets were obtained from Perdue Farms, Inc. (Bridgewater, VA). The nuggets were pre-dusted, battered, breaded and par-fried at a small pilot plant located within the processing facility. One percent methylcellulose was added to the pre-dust before coating the nuggets. The samples were par-fried at approximately 190°C to set the coating. Chicken nuggets were stored in a freezer (-40°C) until needed for the frying experiment.

Frying Experiment

Experiments were conducted using commercial vegetable oil (Bakers & Chefs, North Arkansas Wholesale Company, Inc., Bentonville, AR) as the frying medium. The product samples were taken out of the freezer and immediately fried at 175°C and 163 kPa. Two pressure sources, nitrogen gas and steam released from the food, were used to generate the required pressure in a deep-fat fryer (Model 500C, Henney Penney, Inc., Eaton, OH).

The pressure fryer was modified by adding a nitrogen gas flow system. The exhaust tube which connected the operating valve and the fry pot was replaced by a tee in order to facilitate the flow of nitrogen gas**.** The gas hose from the nitrogen gas tank was connected to the tee which supplied 240 kPa of pressure to the fryer. After the pressure inside the fryer reached a maximum, a safety relief valve connected to the operating valve automatically released the excess pressure to the environment.

Steam released from the food material being fried was the other source of pressure used in this study. In this situation, the amount of pressure supplied to the fryer depends on the amount of the initial fry load. The fry load was kept constant at 1600 g. A typical fry batch using nitrogen gas as the pressure source consisted of approximately 380 g of tested product. The fry batches in which steam was used as the pressure source consisted of approximately 190 g of tested product and 1400 g of chicken breast tenders added as the dummy load. Each of the treatment combinations were fried at the same frying time of 240 s. There was an average 30 s delay in closing and opening the fryer. Samples were held under a heat lamp (model SW-2430, Merco Inc., Lakewood, NJ) at 60°C for 15 minutes before being evaluated by the panelists.

Sample Preparation

A total of three samples were evaluated by each panelist for each of the two tests. Three two-digit codes generated from a random numbers table were assigned to the samples. Plastic 2 oz. soufflé cups were labeled with the two-digit codes. One chicken nugget sample was placed in each of the labeled cups. The samples were presented in balanced, random order. Panelists were instructed by the scorecard (Appendix) as to how to proceed with the test.

Statistical Analysis

Statistical analyses were performed using the General Linear Model (GLM) program of the SAS software system (SAS, 2000). A one-way analysis of variance (ANOVA) test was used to evaluate the data. Fisher's Least Square Difference method was used to estimate differences among the sample means at the 5% probability level (α=0.05).

RESULTS AND DISCUSSION

There were 40 panelists used in this study for both sensory tests. In each of the tests, 75% of the total panel was within the age range of 18-35 and the remaining 25% in the age range of 36-60. The hedonic scale test had nearly equal number of female and male participants while the simple intensity scale test had slightly more female participants. The demographic characteristics of the panelists are summarized in Table 5.1.

From the results of the simple intensity scale test, it was concluded that the three samples were not significantly different ($p<0.05$) from each other as it related to crispness, juiciness, oiliness and flavor. Panelists were unable to distinguish between the samples. These results are not surprising due to the inexperience of the panelists. The subjects that participated in this study were not made familiar with the product attributes prior to testing and therefore, used their own knowledge of the terms to evaluate the samples. Furthermore, panelists may not have been familiar with the scales and how they were to be used, resulting in high variability amongst the panelists. As with the validity and reliability of terminology, the validity and reliability of intensity measurements are highly dependent upon: (1) the selection of a scaling technique which is broad enough to encompass the full range of parameter intensities and which has enough discrete points to pick up all the small differences in intensity between samples; (2) the thorough training of the panelists to use the scale in a similar way across all samples and across time and (3) the use of reference scales for intensity of different properties to ensure consistent use of scales for different intensities of sensory properties across panelists and repeated evaluations (Meilgaard *et al.*, 1999). Similar results were found in a consumer acceptance study on breaded fried poultry products conducted by Mallikarjunan *et al.* (1999). In that study, it was concluded that consumers were not able to differentiate between treatments, as it related to product texture, juiciness and oiliness. Additionally, no preference was noted between control and edible film coated samples.

Although no statistical differences were found among the three tested samples as it related to crispness, juiciness, oiliness or flavor, favorable attribute ratings were given to each of the samples. The mean attribute ratings for the samples are summarized in Table 5.2. The high ratings (7.05-7.50) given to product crispness indicate that panelists did perceive the samples as being crisp, but the magnitude of change in crispness was too subtle to distinguish among samples. The mean ratings for crispness were slightly higher for samples fried using nitrogen gas than those samples fried using steam as the pressure source. Perhaps, a greater number of participants would have clearly shown a significant difference between the samples fried under the two pressure conditions.

In the hedonic test, it was found that the samples were not significantly different from each other; that is, no one sample was more well-liked than the other. However, in general, the samples were fairly well-liked as indicated by mean overall liking ratings that ranged from 5.84-7.32. Upon evaluating the demographic information, it was found that gender had an effect on preference or liking of the samples. The mean values for overall liking based on the response of females were 7.19, 6.9 and 6.14 for control samples fried with nitrogen gas, MC-coated samples fried with nitrogen gas and control samples fried with steam, respectively (Table 5.3). Samples fried with nitrogen gas were given a significantly higher rating for overall liking than those samples fried with steam.

Conversely, there were no significant differences found between control samples fried with nitrogen gas and control samples fried with steam based on the response of male participants. The mean values for overall liking based on the response of males were 6.32, 5.84 and 7.32 for control samples fried with nitrogen gas, MC-coated samples fried with nitrogen gas and control samples fried with steam, respectively (Table 5.3). The control samples fried with steam were given a higher rating for overall liking but were not significantly different from the control samples fried with nitrogen gas. Moreover, males rated product coated with MC and fried with nitrogen gas significantly lower than the control samples fried with steam, indicating that they did not like the MC in the coating.

Although the results did not indicate significant differences in overall liking among the samples, panelists were willing to pay extra money for samples fried using nitrogen gas. Of the 40 participants, 18 (or 45%) were willing to pay a little extra for both the control samples and the MC-coated samples fried using nitrogen. Additionally, of the 18 panelists that were willing to pay more for the control samples fried using nitrogen, 33.3% were willing to pay up to an extra $0.25 while 41% were willing to pay from $0.26 to $1.00 more. For the MC-coated samples fried using nitrogen gas, of the 18 panelists that were willing to pay more, 41.7% were willing to pay up to an extra $0.25 and 33.3% were willing to pay an extra of $0.26 to $0.50.

The results did not indicate significant differences in crispness, juiciness, oiliness, flavor and overall liking among the samples and did not seem to provide any clear advantage of using one pressure source or coating type over the other. However, it has been shown that frying with nitrogen gas does have other advantages. In a study conducted by Innawong (2001), it was demonstrated that frying using nitrogen gas as opposed to steam significantly increased the fry-life of the oil. It was reported that the quality of the oil collected from nitrogen batches after one week were similar to the quality of oil collected from the steam batches after 3-4 days.

The ability of nitrogen to extend the fry-life of the oil can result in huge economic gains for the fast-food industry. Industry not only receives the benefit of saving on the cost of oil, but also does not have to be concerned with compromising other quality attributes of the foods being fried with the nitrogen gas system. The results from the sensory study show that panelists were unable to detect a difference between samples fried using nitrogen gas and those samples fried using steam, suggesting that other quality attributes of the chicken nuggets fried using nitrogen were not compromised. Therefore, there are no issues of diminished product quality as it relates to flavor, juiciness, oiliness and other key attributes of breaded fried foods. Furthermore, panelists were willing to pay more money for samples fried using the nitrogen gas system even though there was no difference in product quality. In this case, industry incurs economic gains as a result of the extended usage of the frying oil and from the ability to charge slightly more for the products fried using nitrogen gas.

Other benefits of using nitrogen as a pressurizing medium include reducing the amount of product waste by allowing the use of smaller fry loads, and also reducing safety hazards associated with traditional pressure frying methods. When using nitrogen, the frying vessel no longer relies on the steam released from the fry load to generate adequate pressure. As a result, as much or as little product can be fried without being concerned with diminished product quality due to inadequate steam generation. Additionally, traditional pressure frying can be dangerous due to the contact between the steam and the hot oil. This contact results in violent bubbling and splattering of the oil which can harm the operator upon opening the fryer lid. The violent splattering oil is not seen to as great of an extent as when frying with nitrogen as the pressurizing medium. Given the results presented in this study and the work done by Innawong (2001), it has been demonstrated that using a nitrogen gas flow system when preparing breaded fried foods is extremely beneficial and economically advantageous.

CONCLUSIONS

There were no statistical differences found among the samples at the 5% probability level. Panelists were unable to detect differences in the samples based on crispness, juiciness, oiliness and flavor. Additionally, no one sample was shown to be more well-liked than another. However, panelists were willing to pay extra money for those samples fried using nitrogen. Gender did have an effect on the overall liking of the samples. The mean ratings for overall liking by the female subjects suggested that they preferred samples fried with nitrogen gas as opposed to steam. Male participants ranked the samples coated with MC and fried with nitrogen gas significantly lower than the control samples fried with nitrogen.

Although there seemed to be no clear cut advantage of using one pressure source over the other, frying with nitrogen gas has other economic advantages. Frying using nitrogen gas results in economic gain due to the extension of the oil fry-life, reduction in product waste from using smaller fry loads and the willingness of consumers to pay a little extra for products fried using nitrogen gas.

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Table 5.1. Demographic information of sensory panelists used in simple intensity scale and hedonic scale tests.

Demographics Characteristics	Range	Percent Participants[1] in test using	
		Simple Intensity Scale	Hedonic Scale
Gender	Male	42.5	47.5
	Female	57.5	52.5
Age			
	18-24	42.5	40.0
	25-35	32.5	35.0
	36-60	25.0	25.0
Annual Income	$25,000 or less	62.5	60.0
	$26,000 - $50,000	25.0	20.0
	$51,000 - $75,000	7.5	12.5
	More than $75,000	5.0	7.5
Frequency of visits to fast-food restaurants[2]	Never	2.5	5.0
	Once	17.5	7.5
	Twice	22.5	20.0
	Thrice	30.0	35.0
	More than thrice	27.5	32.5
Purchase behavior of chicken nuggets or other breaded fried foods at these restaurants	Yes	77.5	75
	No	22.5	25

[1]Values represent percentages out of 40 panelists.
[2]Frequency of visits is on a per month basis, e.g. once/month

Table 5.2. Mean sample attribute ratings using simple intensity scale.

Pressure[1]	Coating	Attribute			
		Crispness[2]	Juiciness[3]	Oiliness[4]	Flavor[5]
Nitrogen	Uncoated	7.50 ± 1.15	6.23 ± 1.87	4.70 ± 1.99	5.75 ± 1.77
	MC	7.40 ± 1.24	5.68 ± 1.90	4.25 ± 1.66	5.78 ± 1.75
Steam	Uncoated	7.05 ± 1.52	5.83 ± 1.75	4.15 ± 1.83	5.33 ± 1.89

[1]All samples fried at 163 kPa.
[2]Ratings: 1 = not crisp/soggy; 9 = very crisp
[3]Ratings: 1 = not juicy; 9 = very juicy
[4]Ratings: 1 = dry; 9 = oily/wet
[5]Ratings: 1 = no chicken flavor; 9 = high chicken flavor

Table 5.3 Mean overall liking ratings (hedonic scale) as influenced by gender.

Gender	Pressure Source[1]	Coating	Rating
Male	nitrogen	Uncoated	6.32 [ac]
Male	nitrogen	MC	5.84 [a]
Male	steam	Uncoated	7.32 [c]
Female	nitrogen	Uncoated	7.19 [c]
Female	nitrogen	MC	6.90 [bcd]
Female	steam	Uncoated	6.14 [ab]

[1]All samples fried at 163 kPa.
[abcde]Means within a column with unlike superscript are significantly different ($p<0.05$).

CHAPTER 6

SUMMARY AND CONCLUSIONS

Edible coatings used on food substrates aid in reducing oil and moisture transfer between the food material and the frying oil during deep fat frying. The coatings act as a thermal barrier to moisture and oil migration, resulting in products that retain more moisture within the core region and contain less fat. The theory behind this study was that if edible coatings can inhibit moisture migration to the crust region and moisture uptake from the environment, then a crispier product could be obtained. The two edible coatings evaluated in this study were methylcellulose (MC) and whey protein isolate (WPI) due to their proven ability to be effective inhibitors of mass transfer.

It is well known and documented that pressure frying produces juicier products than those products fried under atmospheric pressure. Pressure frying relies on the steam/moisture generated from the food material to adequately pressurize the frying vessel. Therefore, it is limited to situations where large fry loads are desired. It would be advantageous to have a pressure frying system that does not rely on the size of the fry load such that each and every fry load resulted in high quality fried products, regardless of the size of the load. The use of nitrogen gas as a pressurizing medium to replace steam released from the product was investigated.

This study was divided into two parts. The primary focus of the of the study was to determine the effects of two edible film coatings (MC and WPI) and two pressure sources (nitrogen gas and steam) on the crispness, texture, moisture and fat content, pressed juice and color of breaded fried chicken nuggets. The main objective of the first portion of this study was to find an objective means of measuring product crispness.

Chicken nugget samples were held under a heat lamp (60°C) for 0, 10, 20 and 30 minutes and evaluated after each time step to determine the effect of the edible coatings and the pressure source on product crispness, texture, moisture and fat content, pressed juice and color. Ultrasonic velocity was used to characterize product crispness.

It found that at the 5% probability level (α=0.05), samples fried with nitrogen gas had significantly ($p<0.05$) higher mean ultrasonic velocity values, suggesting the products were crispier than those fried with steam. Additionally, products coated with MC were significantly different from those coated with WPI. Products coated with MC were crispier. The coating application also had a significant effect on sample crispness. Chicken nugget samples in which the coating was incorporated into the pre-dust were crispier than those samples in which the coating was incorporated into the batter, as evidenced by higher mean ultrasonic velocity values.

Even though the results indicated significant differences in moisture content, fat content and pressed juice, the magnitude of increase in moisture retention, reduction in fat-uptake, or an increase in released juices seems to be very small and did not provide any clear advantage of using one pressure source or coating type over the other. These results could be attributed to a threshold pressure above which the benefit of frying under pressure does not provide a meaningful change in the product attributes. There are however, clear advantages of using nitrogen as a pressurizing medium, and they are economic gain due to the extension of the oil fry-life, reduction in product waste from using smaller fry loads and the willingness of consumers to pay a little extra for products fried using nitrogen gas.

The second part of the study involved using sensory measurements in order to obtain subjective measurements of product crispness, juiciness, oiliness and flavor. Forty untrained subjects were used to determine if sensory differences exist between breaded chicken nugget samples fried with varying treatment combinations. The three treatment combinations used were: (1) samples coated with 3% methylcellulose (MC) incorporated into the pre-dust and fried with nitrogen gas; (2) uncoated samples fried with steam and (3) uncoated samples fried with nitrogen gas. The treatment combinations evaluated in the sensory testing were selected based on the data received from the objective measurements in the first portion of the study. Samples were held under a heat lamp (60°C) for 15 minutes prior to being evaluated by the panelists. A simple intensity scale was used to evaluate product crispness, juiciness, oiliness and flavor while a nine-point hedonic scale was used to determine overall liking of the samples.

It was concluded that at the 5% probability level, there were no significant differences among the three samples tested based on crispness, juiciness, oiliness or flavor. Furthermore, there were no significant differences found among samples based on overall liking. However, it was shown that gender had a significant effect on overall liking of the product. Female subjects preferred products fried with nitrogen gas, as indicated by higher mean ratings for overall liking. Conversely, male subjects did not have a preference. Among the male subjects, products coated with MC and fried with nitrogen gas were ranked significantly lower than the control with nitrogen. Although no significant differences were found, panelists were willing to pay more for samples fried using nitrogen gas.

This study has demonstrated that frying with nitrogen gas as opposed to steam and incorporating an edible film coating (MC was found to be the most effective in this study) into the pre-dust significantly increases the crispness of breaded fried chicken nuggets. Furthermore, using nitrogen and edible film coatings produces breaded fried products that are comparable to or exceeding in quality those samples fried with steam.

For future study, there should be an exploration of using other edible film coatings and also combining various coatings to determine if there is a better coating or combination of coatings that will be more effective at enhancing product crispness. Furthermore, the percentage of edible coatings added to the batter and/or the pre-dust should be explored; that is, MC or WPI may be more effective enhancers of product crispness at other concentrations. It would also be advantageous to study the effects the pressure sources along with the edible coatings on the quality of the frying oil. Finally, a trained sensory panel may provide more accurate results when using sensory analysis to test various product attributes. Alternatively, the number of sensory panelists should be greatly increased to better assess if there are in fact statistical differences among the samples.

APPENDIX

A1. Worksheet for Simple Intensity Test

Date__________________ Test Code: Crisp-1

Each panelist receives three samples in balanced random order. Each sample is coded with a random number.

Type of samples: Breaded Fried Chicken Nuggets

Type of test: Simple Intensity

Code	Sample Identification
12	Control with steam
25	Control with nitrogen
32	MC with nitrogen

Arrange samples as follows on the serving trays:

Panelist No.	Sample Order
1	12 25 32
2	32 12 25
3	25 32 12
4	12 32 25
5	32 25 12
6	25 12 32
7	12 25 32
8	32 12 25
9	25 32 12
10	12 32 25
11	32 25 12
12	25 12 32
13	12 25 32
14	32 12 25
15	25 32 12
16	12 32 25
17	32 25 12
18	25 12 32
19	12 25 32
20	32 12 25
21	25 32 12
22	12 32 25
23	32 25 12

24	25	12	32
25	12	25	32
26	32	12	25
27	25	32	12
28	12	32	25
29	32	25	12
30	25	12	32
31	12	25	32
32	32	12	25
33	25	32	12
34	12	32	25
35	32	25	12
36	25	12	32
37	12	25	32
38	32	12	25
39	25	32	12
40	12	32	25

A2. Worksheet for Hedonic Test

Date__________________ Test Code: Crisp-2

Each panelist receives three samples in balanced random order. Each sample is coded with a random number.

Type of samples: Breaded Fried Chicken Nuggets

Type of test: Hedonic

Code	Sample Identification
78	Control with steam
19	Control with nitrogen
44	MC with nitrogen

Arrange samples as follows on the serving trays:

Panelist No.	Sample Order
1	19 78 44
2	44 19 78
3	78 44 19
4	19 44 78
5	44 78 19
6	78 19 44
7	19 78 44
8	44 19 78
9	78 44 19
10	19 44 78
11	44 78 19
12	78 19 44
13	19 78 44
14	44 19 78
15	78 44 19
16	19 44 78
17	44 78 19
18	78 19 44
19	19 78 44
20	44 19 78
21	78 44 19
22	19 44 78
23	44 78 19

24	78	19	44
25	19	78	44
26	44	19	78
27	78	44	19
28	19	44	78
29	44	78	19
30	78	19	44
31	19	78	44
32	44	19	78
33	78	44	19
34	19	44	78
35	44	78	19
36	78	19	44
37	19	78	44
38	44	19	78
39	78	44	19
40	19	44	78

A3. Scorecard for Simple Intensity Test

Judge Number: ____ Product: Breaded Fried Chicken Nuggets

Instructions:
Bite down on each of the samples with the incisors in the order indicated. Please indicate the intensity of the following attributes of the samples of chicken nuggets.

Sample _____

1. Crispness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Not crisp/soggy **Very crisp**

2. Oiliness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Dry **Oily/wet**

3. Juiciness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
None **Very juicy**

4. Flavor ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
No Chicken Flavor **High Chicken Flavor**

Sample _____

1. Crispness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Not crisp/soggy **Very crisp**

2. Oiliness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Dry **Oily/wet**

3. Juiciness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
None **Very juicy**

4. Flavor ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
No Chicken Flavor **High Chicken Flavor**

Sample _____

1. Crispness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Not crisp/soggy **Very crisp**

2. Oiliness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Dry **Oily/wet**

3. Juiciness ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
None **Very juicy**

4. Flavor ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
No Chicken Flavor **High Chicken Flavor**

A4. Scorecard for Hedonic Test

Judge Number: ____

Product: Breaded Fried Chicken Nuggets

Instructions: Take a bite of each of the samples in the order indicated and determine how well you like the product overall.

Sample 78

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | **Neither like nor dislike** | **Like Extremely**

Would you be willing to pay a little extra for this product you tested? ☐ Yes ☐ No

If you answered yes to the previous question, how much more would you be willing to pay?

☐ $0.01-$0.25 ☐ $0.26-$0.50 ☐ $0.51-$0.75 ☐ $0.76-$1.00 ☐ > $1.00

Sample 19

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | **Neither like nor dislike** | **Like Extremely**

Would you be willing to pay a little extra for this product you tested? ☐ Yes ☐ No

If you answered yes to the previous question, how much more would you be willing to pay?

☐ $0.01-$0.25 ☐ $0.26-$0.50 ☐ $0.51-$0.75 ☐ $0.76-$1.00 ☐ > $1.00

Sample 44

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely | **Neither like nor dislike** | **Like Extremely**

Would you be willing to pay a little extra for this product you tested? ☐ Yes ☐ No

If you answered yes to the previous question, how much more would you be willing to pay?

☐ $0.01-$0.25 ☐ $0.26-$0.50 ☐ $0.51-$0.75 ☐ $0.76-$1.00 ☐ > $1.00

A5. Demographics Questionnaire

Judge Number _____

Demographics Questionnaire

Virginia Polytechnic Institute & State University
Sensory Evaluation of Crispness in Breaded Fried Chicken Nuggets

What is your sex?

☐ Male ☐ Female

What is your age?

☐ 18-24 ☐ 25-35 ☐ 36-60 ☐ Over 60

What is your annual income?

☐ $25,000 or less
☐ $26,000-$50,000
☐ $51,000-$75,000
☐ More than $75,000

On a monthly basis, how often do you eat at fast-food type restaurants?

☐ Never
☐ Once/month
☐ Twice/month
☐ Three times/month
☐ More than 3 times

Do you often purchase chicken nuggets or other breaded fried foods at these restaurants?

☐ Yes ☐ No

A6. MATLAB Code

```
%
% MATLAB code for analyzing the time domain data and calculating time of flight
% Written by Solos Jivanuwong, 2002 for exclusive use in this study
%

function NFn = shiftzero(Fn)
%
% Drop the first 128 data points and shift the time zero accordingly
%
format short e;
a=load(Fn);
b=a([129:1024],:);
error=mean(b(:,2));
shiftv=b(:,2)-error*ones(size(b),1);
c=[b(:,1) shiftv]
plot(c(:,1),c(:,2))
save test1.txt c -ascii


function tof = findtof(Fn1,Fn2)
%
%Fn1 & Fn2 are variables/text files
%
aa1=load(Fn1)
aa2=load(Fn2)
v1=aa1(:,2); plot(aa1(:,1),aa1(:,2))
v2=aa2(:,2); figure; plot(aa2(:,1),aa2(:,2))
[nov1 dummy]=size(v1)
[nov2 dummy]=size(v2)
id=nov1+nov2-1
v1n=[v1;zeros(id-nov1,1)];
v2n=[v2;zeros(id-nov1,1)];
ccf=ifft(fft(v2n).*conj(fft(v1n)))
ccf1=real(ccf);
tof=find(ccf1 == max(ccf1))
figure; plot(aa1([1:151],1), ccf1([1:151],1));
title('Cross-correlation Plot');
realtof=aa1(tof,1)
xlabel(['TOF = ' num2str(realtof)]);
```

A7. Additional Statistical Analysis

Table A7.1. Mean moisture content as influenced by pressure source, coating type and coating application.

Pressure Source[1]	Coating	Application	Moisture (%)	
			Crust	Core
Steam	Uncoated		32.32	63.55
	MC	Pre-dust	30.21	62.63
	MC	Batter	28.83	62.14
	WPI	Pre-dust	31.59	61.29
	WPI	Batter	32.21	61.83
Nitrogen	Uncoated		31.15	62.02
	MC	Pre-dust	33.48	62.31
	WPI	Batter	34.18	61.78
	WPI	Pre-dust	33.39	63.03
	WPI	Batter	32.46	62.78

[1]All samples fried at 163 kPa.
[abc]Means within a column with unlike superscript are significantly different ($p<0.05$).

Table A7.2. Mean fat content as influenced by pressure source, coating type and coating application.

Pressure Source[1]	Coating	Application	Fat (%)	
			Crust	Core
Steam	Uncoated		24.74	17.11
	MC	Pre-dust	23.66	16.10
	MC	Batter	23.91	15.91
	WPI	Pre-dust	27.03	17.41
	WPI	Batter	24.36	16.96
Nitrogen	Uncoated		25.70	17.88
	MC	Pre-dust	25.55	17.37
	WPI	Batter	25.12	18.83
	WPI	Pre-dust	24.69	16.88
	WPI	Batter	25.07	16.10

[1]All samples fried at 163 kPa.
[abc]Means within a column with unlike superscript are significantly different ($p<0.05$).

Table A7.3. Mean pressed juice as influenced by pressure source, coating type and coating application.

Pressure Source[1]	Coating	Application	Pressed Juice (%)
Steam	Uncoated		20.08
	MC	Pre-dust	20.39
	MC	Batter	21.36
	WPI	Pre-dust	17.14
	WPI	Batter	18.06
Nitrogen	Uncoated		15.44
	MC	Pre-dust	22.47
	WPI	Batter	21.75
	WPI	Pre-dust	20.14
	WPI	Batter	24.78

[1]All samples fried at 163 kPa.
[abc]Means within a column with unlike superscript are significantly different (p<0.05).

Table A7.4. Mean ultrasonic velocity as influenced by pressure source, coating type and coating application.

Pressure Source[1]	Coating	Application	Ultrasonic Velocity (m/s)
Steam	Uncoated		342.64
	MC	Pre-dust	196.28
	MC	Batter	170.77
	WPI	Pre-dust	621.69
	WPI	Batter	440.64
Nitrogen	Uncoated		530.90
	MC	Pre-dust	624.91
	WPI	Batter	500.58
	WPI	Pre-dust	446.11
	WPI	Batter	325.16

[1]All samples fried at 163 kPa.
[abc]Means within a column with unlike superscript are significantly different (p<0.05).

Table A7.5. Mean peak load and energy to peak load as influenced by pressure source, coating type and coating application.

Pressure Source[1]	Coating	Application	Peak Load (N)	Energy to Peak Load (N·mm)
Steam	Uncoated		477	2738
	MC	Pre-dust	442	2344
	MC	Batter	480	2456
	WPI	Pre-dust	524	2800
	WPI	Batter	500	2782
Nitrogen	Uncoated		516	2746
	MC	Pre-dust	475	2808
	WPI	Batter	504	2777
	WPI	Pre-dust	440	2261
	WPI	Batter	406	2026

[1]All samples fried at 163 kPa.

[abc]Means within a column with unlike superscript are significantly different ($p<0.05$).

VITA

The author, Tameshia Ballard was born on February 28, 1978 in Wilmington, NC. She graduated with a Bachelor of Science degree in Biological Engineering from North Carolina State University in May 2001. In June of 2000, Tameshia had an opportunity to participate in a National Science Foundation (NSF) summer internship at Virginia Polytechnic Institute & State University. In August 2001, she entered Virginia Tech to pursue a Master of Science degree in Biological Systems Engineering under the direction of Dr. P. Kumar Mallikarjunan. She completed the final exam for the degree in September 2003.