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Fat Uptake Reduction in Deep-Fried Chicken Breast

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Fat Uptake Reduction in Deep-Fried Chicken Breast

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Lovie G. Matthews received her bachelor's degree in Chemistry in 2016 from North Carolina Central University. She began the pursuit of her master's degree in Food and Nutritional Sciences in 2017. She published one review paper from her work in Trends in Food Science and Technology (Impact: 6.609; Rank: 3/135) in 2018 and co-authored a book chapter to be published soon. She plans to submit two manuscripts from her thesis research to indexed food science journals. Her goal is to work as a food scientist in Product Development and continue her studies as a PhD candidate in Food Science or Biochemistry. She also plans to develop nutrition based mobile apps to help young and seasoned elderly lead healthier lives.

Dedication

I would like to dedicate my work to my grandmother and immediate family, who have supported me through this journey. Their passions for living, education, and fulfilling a dream have given me a gleaming faith in humanity and a foundation for generations to come.

Acknowledgments

First, I would like to thank my ancestors who prayed diligently for my siblings and me. I would also like to thank my support system (Camela, Gideon, and Lanetta) for encouraging and showing me what real freedom is like. I would like to express my gratitude to Dr. Reza Tahergorabi for his support of my research and writing. I would also like to thank Dr. Roberta da Silva and Dr. Abolghasem Shahbazi for their support in my thesis development. Lastly, I would like to thank Daniel for his assistance and encouragement.

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AOAC	Association of Official Analytical Chemists
BRFSS	Behavioral Risk Factor System
°C	Degrees Celsius
CDC	Center for Disease Control and Prevention
CPI	Chicken Protein Isolates
ddH_2O	Distilled deionized H_2O
FSIS	Food Safety and Inspection Service
HCl	Hydrochloric acid
HPMC	Hydroxypropyl Methylcellulose
IRB	Institutional Review Board
ISP	Isoelectric Solubilization/ Precipitation
MC	Methylcellulose
mg	Milligram
MSG	Monosodium Glutamate
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide
pI	Isoelectric point
TiO_2	Titanium Dioxide
WHO	World Health Organization

Abstract

Obesity is the deposit of excessive adipose tissue on the body due to the overconsumption of nutritionally inadequate foods. The fat in the deep-fat fried chicken is derived from the oil absorption during frying. High consumption of deep-fat fried foods may lead to cardiovascular diseases and obesity. The main objectives of this experiment were to reduce the fat uptake in deep-fat fried chicken breast by developing an edible coating made of chicken breast protein isolates (CPI) as well as replace the corn starch in batter with sweet potato starch to further examine the quality attributes of the battering systems.

In this study, edible coatings of various concentrations (5%, 10%, and 15%) were prepared from CPI using isoelectric solubilization/precipitation (ISP). Chicken breast samples coated, battered, breaded and deep-fried. Then, fat uptake was measured using the Soxhlet method. Moisture content, color, texture, pH, ash, and the frying yield were also measured. A sensory evaluation was completed as well to examine the quality attributes of the edible-coated samples in comparison to the control and commercial battered samples.

The sweet potato starch batter system coated with 15% protein, resulted in the highest reduction in fat uptake and lowest moisture loss, i.e., 8% and 37%, respectively. Coated samples had lower L* and b* values in comparison to the control and commercial batter. Coating treatments had no significant effect ($p > 0.05$) on pH values. The puncture force of the samples varied among treatments. Overall, the highest puncture force occurred in the sample with commercial batter and the lowest puncture force occurred in the sweet potato batter treatments. Coating treatments positively affected the frying yield, increasing the yield from 57% in the sample with no breading and no coating to 84% and 87% in the samples with 15% protein coating. The results of this study

suggest that chicken protein-based edible coating in combination with sweet potato starch in batter will result in lower fat-uptake and improving other quality attributes of the deep-fat fried chicken.

CHAPTER 1

Introduction

1.1 Fried Foods: Tasty yet Problematic

For the past 30 years, obesity rates have been on the rise. Healthcare costs associated with obesity and chronic diseases have increased as well, attributing nearly $147 billion to nearly $210 billion towards the national debt (Cawley & Meyerhoefer, 2009). Obesity is defined as substantial weight gain due to genetic and environmental conditions, further causing chronic disease such as high blood pressure, diabetes, and heart disease (Chan & Woo, 2010). Cardiovascular disease, a series of heart related conditions, can be caused by the consumption of high density, nutritionally inadequate foods, such as fried foods. French fries, deep-fried chicken, and chicken nuggets have become common staples in the American diet, as they are more accessible than home meal preparation due to socioeconomic status and convenience (Ananey-Obiri, Matthews, Azahrani, Ibrahim, Galanakis, & Tahergorabi, 2018; Ogden, Lamb, Carroll, & Flegal, 2010). Fried foods also attribute to a greater intake of energy, total fat, saturated fat, and sugar (Powell & Nguyen, 2013). While palatable, deep-fried foods can cause serious health consequences due to its fat content. The fat content is derived from oil absorption during frying. A series of reactions occur during frying, but the oil's contact with the surface of the food product can yield variable oil absorption. Increased contact time between the food and the frying oil causes a higher heat transfer to the food and water migration from the core to the exterior of the fried food (Kita, 2014). Various studies have indicated a variety of methods that can reduce oil absorption in deep-fried foods (Brannan et al., 2014; Moreira, Sun, & Chen, 1997; Williams & Mittal, 1999). Frying processes such as blanching, pre-drying, battering, and coating a product's surface with various substances provide a barrier to fat absorption.

1.2 Frying Processes to Reduce Fat Absorption

Blanching is a thermal process used to enhance food. During frying infrared dry- blanching delivers heat causing dehydration and reduced oil absorption (Moyano & Pedreschi, 2006; Bingol, Zhang, Pan, and McHugh, 2011). Pre-drying the product can reduce oil absorption, as the moisture content of the food is contained in the interconnected pore space created during frying, and an inner pore space can create a temporary matrix that reduces moisture loss (Rahimi & Ngadi, 2014). Although these processes have been used, researchers have had problems with these methods. For instance, with pre-dry frying and blanching, an increase in frying temperature results in an increase in moisture loss and fat uptake (Debnath & Rastogi, 2003; Sobukola, Awonorin, Sanni, & Bamiro, 2008). High temperatures are required for deep-frying meat products, as adequate food safe temperatures must be reached in a short period of time (FSIS, 2013).

Coating and battering before frying create protective barriers that is influenced by the interaction with heat. The ingredients in the batter create a network structure that prevent moisture loss and reduce fat absorption (Adedeji, Liu, & Ngadi, 2010). Like battering, an edible coating can provide the same benefits. An edible coating is a protective layer made of edible materials, such as proteins. The effectiveness of the coating is determined by its mechanical and barrier properties, which depend on its composition and microstructure (Ananey-Obiri, et al., 2018). The edible coating made of myofibrillar proteins forms a gel-like structure due to denaturation. The film-forming properties are an adequate barrier for oil absorption (Iwata, Ishizaki, Handa, & Tanaka, 2000). An edible coating as well as an adequate batter system can create a significant barrier to reduce moisture loss and decrease fat uptake.

1.3 Objectives and Hypotheses

There was a dual objective for this study. The first objective was to examine the efficiency of the chicken-based protein coating in fat uptake reduction. The second objective was to investigate the effect of the batter application (corn starch v. sweet potato starch) on the quality attributes of the deep-fat fried chicken breast. These quality attributes included color, texture, pH, frying yield, and sensory evaluation. Based on these objectives, the following hypotheses can be formulated.

Hypothesis 1: If the chicken protein based edible coating is effective, there will be a reduction in the fat uptake.

Hypothesis 2: If the corn starch in the batter is replaced with sweet potato starch, the deep-fat fried chicken breast will have better quality attributes.

CHAPTER 2

Literature Review

2.1 Fried Food Consumption and the Impact on Human Health

For the past three decades, obesity rates have reached a staggering number worldwide. In 2016, an estimated 1.9 billion adults were overweight (18 years or older), with 650 million being obese (World Health Organization, 2017). Obesity increases the risk of chronic diseases such as diabetes, kidney disease, and heart disease (Hilliard, 2010). The latest data from the US National Health Center for Statistics (2016) show that 38% of adults (20 years and older) are obese- over 60 million people. Further data from the Behavioral Risk Factor Surveillance System (BRFSS) in 2015, show that obesity rates in the United States are greater in Southern states among non-Hispanic African Americans, with North Carolina having a 40.2% rate. Certain indicators exist that put African-Americans at greater risk of obesity. These include income, due to the unaffordable prices of nutritious foods, and access due to a lack of safety in more urban areas preventing physical activity (Hilliard, 2010). An influx of fast food restaurants exists in Southern states, making frequent consumption of nutritionally inadequate foods a norm (Center for Disease Control, 2010). Among this population, there is a frequent consumption of fried foods, specifically fried chicken. Fast food fried chicken has an overall tendency to contain few nutrients, but higher amounts of carbohydrates, sodium, and fat (Kushi et al., 2012). These alarming trends suggest the need for reduced fat fried foods.

2.1.1 Popularity of Fried Chicken

Deep-fried foods are popular worldwide, as evidenced by the multi-billion-dollar market and growth of nationally recognized fast food chains (Kassama, 2003). French fries, potato chips, and other delectables are readily available at any time of the day depending on the neighborhood

(Anderson & Matsa, 2011). Chicken's popularity has grown overall due to its content as a healthier choice, a lessened involvement in more recent outbreaks, many variable options, and the influx of fast food with significant taste appeal (National Chicken Council, 2017). The consumption of chicken has grown to 91 pounds per year per person from 83 pounds in 2014 (National Chicken Council, 2017). Restaurants such as Bojangles' ($1.2 billion), Chick-Fil-A ($7.9 billion), Popeyes ($2.9 billion), and KFC ($4.5 billion) have shown significant increases in sales, citing assorted options and catering as factors in their growth (National Restaurant News, 2017). Fried chicken, even though palatable in its tenderness and crunchy crust, can cause serious health consequences due to its fat content (Valerma & Fiszman, 2011). The fat content is derived from oil absorption during frying. A series of reactions occur during frying, resulting in a fully cooked product, but variable oil absorption depending on the oil's surface contact with the chicken.

2.2 Oil Absorption in Deep-Fried Foods

Oil absorption is affected by various properties of the food product and its coating, including the food surface area, moisture content of the food, and types of battering materials. The surface area of food determines the heat transfer during cooking (Ziaiifar, Achir, Courtois, Trezzani, & Trystram, 2008). With a decreased surface area (i.e. cubes of steak), heat transfers quickly resulting in reduced moisture loss. With increased surface area and decreased product thickness, heat transfer slows down leading to more contact between the oil and water vapor on the surface of the food causing increased oil absorption. The outer layer of the food must have low moisture content to reduce the fat uptake (Mellema, 2003). The structure of chicken contains striated muscle fibers with random orientation which contributes to a more uniform pore distribution (Jezek et al., 2009; Kassama, 2003). This distribution adheres more evenly to smaller particles in the batter, reducing oil absorption and indicating an emphasis on the batter formulation (Jezek et. al., 2009).

Properties of the batter can help aid the reduction of fat uptake in fried foods. Previous studies have cited the use of gellan gum, and various mixtures of protein and non-protein hydrocolloids in the batter (Brannan et al., 2014; Moreira, Sun, & Chen, 1997; Williams & Mittal, 1999). Influence of the batter ingredients on the quality of the product will be emphasized in the Methodology and Discussion sections.

2.2.1. Mechanism of oil absorption

Oil absorption is proposed through three mechanisms- water replacement, cooling phase effect, and the surfactant theory of frying. The water replacement mechanism is described as the replacement of evaporated water with cooking oil. The cooling phase effect is described as oil absorption after the food is fried and removed from hot oil (Brannan et. al., 2014). The surfactant theory of frying attributes increased oil uptake to the repeated forming of surfactants, a mixture of polar compounds.

2.2.1.1. Water replacement

The steam causes pores to form on the surface of the food. As more pores form, the vapor pressure increases, leading to oil entering the food. This mechanism is mentioned in other studies as the condensation mechanism (Mellema, 2003; Rice & Gamble, 1989; Southern, Chen, Farid, Howard, & Eyres, 2000). Higher moisture content of the food contributes to the formation of different sized pores. When food is cooked for a longer period, the flow of vapor stops, making the pores completely saturated with oil. Southern et. al. (2000) examined oil uptake before and after frying to better understand the mechanism by using different cuts of thinly sliced potatoes (flat or ridge cut). The potatoes remained rigid during frying, due to their shape and this affected the quantity of oil uptake. Additionally, in flat potatoes the assumed maximum oil uptake when oil replaces the water in the surface pores can be determined by temperature, whereas the maximum oil uptake when based on the solid content of the foods can determine the mechanism of oil absorption.

2.2.1.2. Cooling- phase effect

As previously stated, the cooling-phase effect describes the oil absorption after removal from the frying medium. When the fried product is removed from the oil, the vapor pressure of the pores in the crust's surface decreases, leading to oil rapidly moving into the pores. Oil intake by this method depends on the crust microstructure and oil viscosity, which can be further explained by surface chemistry (Brannan et al., 2014). Liquids with various affinities for solids can be described by wetting. Low affinity for the solid forms beads on the surface, while high affinity for the solid forms a film on the surface. Oil forms a film on the crust of the fried product indicating a higher capillary force and better wetting. When the product is removed from the oil, the microstructure of the crust is determined by maximized interfacial tension between the solid and liquid. Mellema (2003) described this same phenomenon as the capillary mechanism. Balanced interfacial tension begins the process of oil absorption after removal from the oil. Oil viscosity determines the velocity of oil absorption, as a higher viscosity and narrow pores lead to less oil uptake. Oil viscosity is difficult to determine with non-homogenous pores via the capillary mechanism. As described by Ziaiifar et al. (2008), different studies with varied models of oil uptake have conflicting factors regarding what contributes to oil uptake. Modifications of frying techniques include the shaking and draining of fried foods (Bouchon & Pyle, 2005; Mellema 2003; Ouchon & Pyle, 2004), careful monitoring of frying temperature and oil degradation (Math, Velu, & Nagender, & Rao, 2004) and altering the surface of the food by reducing the surface area (Goni

& others 1997; Moreira & Barrufet, 1998) or covering the surface with lipid barriers (Mah, 2008). As a result, these models are not applicable to all factors affecting oil absorption.

2.2.1.3. Surfactant theory of oil absorption

As the oil degrades during frying, the composition of its' contents changes to more polar compounds. These compounds act as wetting agents to lower the interfacial tension between the liquids and increase the foaming tendency of the frying oil. Surfactant formation (polar compounds) heightens the contact between the substrate (food) and the frying oil, resulting in excessive absorption. Surfactant formation also affects the heat transfer at the oil–food interface as contact time increases. Further heat transfer causes dehydration at the surface and results in water migration to the exterior of the fried food (Dana & Saguy, 2006). Previous studies by Gil and Handel (1995) and Tseng, Moreira, and Sun (1996) contradicted the basis

of this theory. Results from those studies showed that surface tension and interfacial tension are not affected by frying time. Higher oil uptake during extended frying is possibly affected by increased oil viscosity due to the polymerization reactions (Tseng et al., 1996).

2.3 Properties of Batter Formulation

Batter is a liquid dough normally consisting of flour and water, but now contain more ingredients to enhance critical properties of the product during frying. Batter is used to provide both a protective layer for the product when frying and a crust that adds flavor, texture, and appearance to the product. Because the crust is of key importance to consumers, obtaining the proper batter formulation is critical for maintaining the food product and gaining consumer confidence. Ideal batters have similar characteristics to wheat flour because of its properties. Core properties of the batter such as moisture (water) content, surface roughness, porosity, particle size in the batter, and viscosity affect the batter pickup (Fiszman & Salvador, 2003). Without a battering system, the original product’s properties have lessened protection against oil absorption. French fries and eggplant cubes were shown to have an increased oil uptake due to a moisture content of more than 40% (Ziaiifar et al., 2008). Moisture content attributes to the product’s density, which causes void volumes due to water escape and leaving space for oil absorption. Moisture content is described as the amount of water naturally present in food product. A lower level of moisture helps with batter pick-up, by acting as an adhesive. Surface roughness is a characteristic determined by fractal geometry after frying. Increasing surface area increases roughness, as indicated in a 2010 study by Moreno, Brown, and Bouchon. Surface roughness was compared after frying wheat flour and potato flake products to determine the impact on oil content. Both products showed a reduction in roughness and oil content when other ingredients were added to the batter. Measurements were taken using topography with relative scales. Potato flake products overall showed more roughness, and the wheat flour was deemed less likely to be rough. However, if the wheat-based product developed roughness during frying, greater oil absorption occurred. This indicates that a relationship exists between surface roughness and oil absorption among products with similar composition, and that other microstructure factors can affect oil absorption. Porosity is defined as the formation of pores or empty spaces in fried foods (Adedeji, 2010). This occurs due to the changes in the microstructure of the product as it is fried, and is quantified by characteristics such as pore size, pore area, and permeability. Reduced porosity is attributed to maximum oil uptake, which reduces the volume of pore space and varies among mixture formulations (Jezek et al., 2009). Particle size can cause variable adhesion. Smaller particle size produced stronger coating adhesion and absorbed more moisture due to a greater surface area (Maskat & Kerr, 2003). Viscosity determines the product handling during and after coating (Varela & Fiszman, 2011). Viscosity also determines the quantity of batter that adheres to the product and is determined by the batter's quality of ingredients. Viscosity of the batter, therefore, affects oil absorption. Low viscosity results in increased oil uptake, while high viscosity does the opposite. Including hydrocolloids, and mixtures of starches, gums, and proteins can absorb moisture and help to form structure that aid in retaining the crispiness of the batter.

2.3.1 Corn starch versus sweet potato starch

Starches function as binding, texturizing, and stabilizing agents in batter systems for fried food. The food industry uses modified resistant corn starch in batter, which changes its amylose content. Corn starch with increased amylose concentration obtained the highest maximum force among rice, wheat, and potato starch- changing the mechanical properties of the crust (Pinthus, Singh, Saguy, & Fan, 1998). This was further supported by Rovedo, Pedreñto-Navarro, and Singh (1999), who measured moisture and oil content of a corn starch patty to examine their influence on mechanical behavior. Amylose released during frying of the patty, changed the texture of the granules, making a more structured, elastic shape. However, corn starch granules' have assorted sizes and shapes, meaning that batters including this ingredient are more susceptible to damage during processing resulting in a loss of gelatinization and increased retrogradation (Fiszman & Salvador, 2003; Parada & Aguilera, 2011). These factors affect the structural transformation and its performance during frying, resulting in an undesired sensory product.

The starch from potato has a high viscosity, which makes it preferable for the manufacture of adhesives (Nwokocha, Aviara, Senan, & Williams, 2014). Use of sweet potato starch in the batter provides many benefits regarding processing, packaging, and increasing nutritional content (Bhosale, Biswas, Sahoo, Chatli, Sharma1, & Sikka, 2011). Sweet potato is inexpensive, readily available, and rich in fiber, minerals, and bioactive compounds (Issa, Ibrahim, & Tahergorabi, 2016). Sweet potatoes have potent antioxidant activity due to the presence of vitamin C and beta-carotene (Bhosale et al., 2011).

In comparison to cereal starch, sweet potato starch conveys a desirable texture, enhanced water-binding capacity, reduced cost of the production and improved nutritional value of the fried food (Serdaroglu, Yildiz-Turp, & Abrodimov, 2005; Nwokocha et al., 2014; Viuda-Martos, Ruiz-Navajas, Fernandez-Lopez, & Perez-Alvarez, 2010). Sweet potato starch was shown to improve nutritive value, reduce microbial growth, and had an improved acceptability amongst consumers when applied to shrimp with thyme essential oil (Alotaibi & Tahergorabi, 2018) and as a biodegradable film for baby spinach (Issa, Ibrahim, & Tahergorabi, 2016).

2.4 Methods for Reduction of Oil Absorption

Because of the various properties that are involved in oil absorption, many methods have been used to reduce oil absorption. They include coating formulation of the batter, and the use of edible coatings. An edible coating is a thin layer of edible material applied to the food surface in addition to a protective coating. Functional ingredients are chosen based on enhancing properties that contribute to reduced oil absorption. These ingredients have been used on a wide variety of fried foods, including vegetables, potatoes, and chicken nuggets. Regarding using carrots in batter, carotenoid levels of carrots (with added sodium metabisulfite) were increased based on frying temperature and showed no change based on the type of oil and sensory characteristics (Sulaeman, Keeler, Giraud, Taylor, Wehling, & Driskell, 2001). While using a thick restructured potato mixture (20 % potato starch and 80% potato flake), a smooth, structured surface was created when frying resulting in a solid, denser, and less permeable outer layer. This allowed the oil to drain easily from the surface, thereby reducing oil absorption (Bouchon, Aguilera, & Pyle, 2003). Blanched cassava slices, cooked using vacuum frying, showed decreased oil absorption due to a reduction in the porous space (García-Segovia, Urbano-Ramos, Fiszman, & Martínez-Monzó, 2016). Depending on the ingredients, the batter forms an adhesive surface and minimizes water loss. Elasticity, functionality of its proteins, and moisture contribute to the product's overall acceptability. Examples of these ingredients include wheat flour, and various gums. As stated by Thanatuksorn, Kajiwara, and Suzuki (2009), wheat flour contains starch and gluten, which both formed gels that expanded to form pores. These large pores caused shrinkage of the initial surface, facilitating decreased oil absorption. Hydrocolloid gums support the physical and chemical bonding of food coatings to food substrates by forming gels (Varela & Fiszman, 2011). Various concentrations of gums such as xanthan and arabic improve adhesion, even though higher concentration is not synonymous with significant differences in adhesion. Edible coatings classified according to structure help to obtain the necessary functional properties for the food product. Several non-protein and protein-based coatings exist and their prior use in various experiments support this finding (Albert & Mittal, 2002; Mellema, 2003; Salvador, Sanz, & Fiszman, 2005; Vu, Hollingsworth, Leroux, Salmieri, & Lacroix, 2011).

2.4.1 Non-protein-based coatings

Non-protein-based coatings have a wide variety of uses in food packaging and for protection against microbes. They include polysaccharides, cellulose derivatives, lipids, and gums. Their use in reducing oil absorption occur through thermally induced gel formation, increasing surface hydrophobicity, and film formation. Hydroxypropyl methylcellulose (HPMC) and methylcellulose (MC) uses in various concentrations from 1% to 3% are suitable for edible coatings because they are easily available, odorless, tasteless, and water soluble (Kurek, Scetar, & Galić, 2017). These coatings form a gelled protective layer that minimizes the transfer of moisture and fat from the sample and frying medium. According to Albert and Mittal (2002), pectin lowered water loss in cassava root. In its use on French fries in combination with gums, the high moisture content remained, in addition to reductions in oil absorption (Mahajan, Sonka, & Surendar, 2014). Pectin's use in combination with calcium in controlled ratios during predusting, the batter or the breading inhibits oil absorption (Brannan et al., 2014). Guar and xanthan gums vary in their functional use as a coating for potato chips in various concentrations. Guar gum enhances the barrier properties of fried potato chips by lowering the formation of pores and cracks in the food. Xanthan gum's high viscosity and high-water binding capacity contribute to its good film forming properties, hence the reduction in fat uptake of potato chips and banana slices by 24.8% and 17.2%, respectively (Garmakhany, Mirzaei, Nejad, & Maghsudlo, 2008; Sothornvit, 2011).

2.4.2 Protein based coatings

Protein based coatings formation involve denaturation to achieve gelation. Changes in temperature, and pH, increases in the interface area, or the addition of certain solvents can initiate denaturation. During denaturation, the exposed side chains form spherical aggregates that create the gel network (Brannan et al., 2014). The ratio of denaturation to aggregation determines if the gel will be thick or thin and have a small or large water capacity (Brannan et al., 2014). Plant protein isolates, such as whey and soy, show frequent use in edible films. Whey protein, soy protein, egg albumin, and sodium caseinate were shown to reduce oil absorption from 17 % to 37.5% on different fried muscle foods (Brannan et al., 2014). The specific proteins in whey and soy contribute to variations in functionality. Whey protein isolate contains 90% or more protein. The major proteins are α-lactalbumins, β-lactoglobulins, bovine serum albumin, immunoglobulins, and proteose-peptones, of which β-lactoglobulins are the most present (Zink, Wyrobnik, Prinz, & Schmid, 2016). β-lactoglobulins have hydrophobic centers and α-lactalbumins have great flexibility, which lead to aggregation. Soy protein isolates contain globulins such as glycinin, which acts as a gelation agent. Globulins exist as protein subunits associated by hydrophobic and hydrogen bonding, affecting aggregation as well. Both β-lactoglobulins and glycinin form disulfide bonds when denatured, affecting the tensile properties of the film (Dangaran, Tomasula, & Qi, 2009). Whey and soy protein do not always influence fat reduction in muscle foods, hence the use of soluble protein isolates extracted from the muscle of various species (Dragich & Krochta, 2010).

2.4.2.1 Muscle food proteins

Muscle foods are a group of animal meats containing myofibrillar proteins. Proteins from this group (myosin and actin) constitute gels. As stated previously, gelation occurs after denaturation and aggregation. By understanding the factors that influence gelation, an optimal environment for gel formation can occur. Factors mentioned by Dong, Sun, and Holley (2010) include an examination of how myosin and actin in different animal species react, and how physicochemical properties such as pH, ionic strength, processing parameters, protein concentration, temperature, and additives like transglutaminase, or non-protein additives influence gel texture. The effects of these factors specify that pH, temperature, interaction of myosin and actin in the type of muscle, and protein concentration were the most important among gelation properties (Dong, Sun, & Holley, 2010). At an optimal pH of 6 and temperature range of 55 to 75°C, more cohesive actomyosin gels were formed. Chicken received maximum gel strength within these ranges and a protein concentration of 12.97 mg/mL (Cofrades, Lopez-Lopez, Solas, & Jimenez-Colmenero, 1997). Studies have also shown a difference in the functional behavior of dark (red) and light (white) muscles during thermal processing, mostly attributed to isoforms of myofibrillar proteins (Maesso, Baker, Vadehra, 1970). Because red muscle contains catalysts for lipid and protein oxidation, heme protein and inorganic iron, there is the possibility of deterioration in myofibrillar proteins during processing. Liu and Xiong completed an examination of this problem in a 1996 study. They could not attribute the functional properties of the different muscle types to rheological properties; reinforcing the studies by Maesso, Baker, and Vadehra, 1970; Xiong, 1992; Xiong, 1994.

2.4.2.2 Characteristics of chicken protein isolates recovered with isoelectric solubilization/precipitation

Isoelectric solubilization and precipitation (ISP) is a technique used to isolate specific proteins from unwanted materials (skin, bone, etc.). Hultin and Kelleher (1999) developed this procedure to recover proteins. The proteins are solubilized under dilute alkaline conditions and a centrifugation step separates the fat, water, and protein from the unwanted materials (insolubles). The isoelectric point (pI), when the net charge of the proteins is zero, is reached after less alkaline conditions occur through the addition of hydrochloric acid (HCl). This process was previously applied to beef heart, various species of fish, turkey, and chicken (Chen et al., 2007; James & DeWitt, 2004; Liang & Hultin, 2003; Menezes et al., 2015; Sun et al., 2013; Zhong et al., 2016, Tahergorabi et al., 2012). The isoelectric point of chicken occurs at a pH of 5.5. During ISP with chicken, sarcoplasmic proteins are mostly lost. Therefore, the ISP-recovered proteins contain mainly myofibrillar proteins (Tahergorabi, Sivanandan, & Jaczynski, 2011). Using this method to isolate chicken protein helps eliminate by-product waste. Other properties and treatments, such as water holding capacity, and acid and base treatments can affect the film-forming properties of the gel.

2.4.2.3. Film forming properties of chicken-based protein

Proteins from chicken can form edible films for various uses, including as an edible coating (Paulo, dos Santos, & García, 2005). The assorted use of these films is due to mechanical and viscoelastic properties of the protein isolates, such as water holding capabilities and protein types in the gel. Water holding capabilities determined the adhesiveness of the chicken protein isolate (CPI) gel. Zhao et al., (2016) determined that a 1% NaCl concentration produced optimal texture and water holding capabilities. The gel network of the samples from this concentration produced a "continuous network with thinner fibrous strands and smaller pores." In comparing acid and base treatment of the CPI gels, it was concluded that the emulsion composite gels with the presence of fat obtained higher sensory quality scores. Also, because of fat retention capacity, the alkali-aided protein had a higher emulsion stability than the acid-aided protein. The functional properties of base treated protein gels were significantly better than the emulsion gels, aiding in manufactured composite meats.

As stated earlier, muscle food proteins contain myofibrillar proteins that are classified based on function and color. Myofibrillar proteins typically exhibit excellent thermal gelation, however, red and white myofibrillar proteins differ, as white proteins form more rigid gels (Xiong & Blanchard, 1994). Also, the formation of the film depends widely on pH, as the network of the protein isolates in the gel are affected. Chicken contains concentration-dependent differences in their gelation properties at low, intermediate, and high protein concentrations (Lesiów and Xiong, 2001). In dark muscle, like chicken drumstick, low protein concentrations at 2.5% or less, exhibited poor aggregation due to a higher onset temperature and a greater rate of aggregation. In another study, titanium dioxide (TiO_2) was added to the aid in the reduction of thermal denaturation of the dark muscle (red myofibrillar proteins) gel-improving gel strength, cohesiveness and color, indicating the benefits of its usage in chicken drumstick (dark meat) processing. Overall, in the isolation of chicken protein using white versus dark meat, the isoelectric point must be met to cause hydrophobicity. Controlling thermal processing is essential to the development of a viscoelastic gel matrix in both white and dark meat chicken. This is the prerequisite for efficient protein separation and effective film properties (Tahergorabi, Beamer, Matak, & Jaczynski, 2011). In this study, white meat chicken breast was used for ISP.

CHAPTER 3

Methodology

The objective of this study was to reduce the fat uptake in deep-fried chicken breast with an edible coating and batter variation applied among various treatments. In addition, the effect of the batter variation was examined through physicochemical tests- moisture content, fat, texture, color, pH, and frying yield as stated in objective 2. Sensory analysis was conducted with the approval of the Institutional Review Board (IRB). The quality attributes of the fried chicken breast samples were tested among students (*n=7*) on two different days and analyzed using statistical analysis. Tables 1 and 2 indicate the various treatments and contents.

Table 1

Treatment Groups with Corn Starch Batter and Edible Coating

Treatments	**Commercial Batter**	**Corn Starch Batter**	**Chicken Protein Based Edible Coating**	**Breading**
CS CN	No	No	No	No
CB	Yes	No	No	Yes
CS	No	Yes	No	Yes
CS 5%	No	Yes	5%	Yes
CS 10%	No	Yes	10%	Yes
CS 15%	No	Yes	15%	Yes

CS CN- corn starch batter control with no breading, no coating, and no battering

CB-commercial batter

CS-corn starch batter with no coating

CS 5%-corn starch batter with battering, 5% coating, and breading

CS 10%-corn starch batter with battering, 10% coating, and breading

CS 15%- corn starch batter with battering, 15% coating, and breading

Table 2

Treatment Groups with Sweet Potato Starch Batter and Edible Coating

Treatments	**Commercial Batter**	**Sweet Potato Starch Batter**	**Chicken Protein Based Edible Coating**	**Breading**
SP CN	No	No	No	No
CB	Yes	No	No	Yes
SP	No	Yes	No	Yes
SP 5%	No	Yes	5%	Yes
SP 10%	No	Yes	10%	Yes
SP 15%	No	Yes	15%	Yes

SP CN- sweet potato starch batter control with no breading, no coating, and no battering

CB- commercial batter

SP- sweet potato starch batter with no coating

SP 5%- sweet potato starch batter with battering, 5% coating, and breading

SP 10%- sweet potato starch batter with battering, 5% coating, and breading

SP 15%- sweet potato starch batter with battering, 5% coating, and breading

3.1 Chicken Sample Preparation

Fresh boneless, skinless chicken breasts were purchased from the local grocery store. The chicken was refrigerated until used. The chicken was ground using the meat grinder (LEM grinder, Grinder-0.35 HP, West Chester, OH, USA) with a hole diameter of 0.5 cm. Ground chicken was used to develop the edible coating by the isoelectric solubilization/precipitation (ISP) method, for protein quantification in the Bradford protein assay, and after frying for physicochemical evaluations. Ten grams (10 ± 1 g) samples were cut and used for frying and subsequently physicochemical tests.

3.2 Salt Washing

Ground meat was homogenized with 5 vol. of cold 0.05 M NaCl (2–4 °C) at a speed of 13,000 rpm for 2 min, using a homogenizer (OMNI International, Kennesaw, GA, USA) followed by centrifuging at 5000 x g for 20 min at 4 °C, using a refrigerated centrifuge (Thermo Fisher Scientific, Model ST 16 Centrifuge Series, Asheville NC, USA). The salt-washing process was repeated twice to help facilitate the removal of fat. The washed ground meat obtained, was used for protein isolation. Washed chicken was homogenized with deionized water (dd H_2O) at 1:6 ratio (washed meat: water, w: v) for 5 minutes. The temperature was controlled at 4 °C during recovery by placing the container in an ice bucket.

3.3 Protein Isolation

ISP has been used to solubilize protein in extreme pH conditions (higher than 10.5) and recover protein at isoelectric point (pI). According to Tahergorabi, Beamer, Matak, and Jaczynski (2012):

"The homogenization was continued during the subsequent pH adjustment steps. The homogenate pH was adjusted to 11.50 ± 0.05 with 10 N NaOH. The pH 11.50 ± 0.05 was held for

10 min followed by centrifugation at 5000 x g and 4 °C for 20 min using a refrigerated centrifuge. The centrifugation resulted in three layers: chicken fat (top), chicken muscle protein solution (middle), and insolubles (bones, skin, insoluble proteins, membrane lipids, etc.) (bottom). The pH of the muscle protein solution was adjusted to 5.50 ± 0.05 by 6 N hydrochloric acid to isoelectrically precipitate the proteins. The pH 5.50 ± 0.05 was held for 10 min. The precipitated protein solution was de-watered by centrifugation as above. The centrifugation resulted in two layers: process water (top) and precipitated, de-watered chicken muscle proteins (bottom)." The precipitated and de-watered proteins was collected and used in the development of the edible coating.

3.4 Protein Determination

The Bradford protein assay was used to measure the protein concentration of an unknown sample based on serial dilutions. The binding of protein molecules to the Brilliant Blue G-250 Coomassie dye under acidic conditions results in a color change from brown to blue. Serial dilutions were made with BSA Albumin (10 mg) and 0.1M NaOH in 3.5% NaCl solution. Dilutions ranged from .09375 mg/mL to 3 mg/mL. Samples of the ground chicken and protein isolate were homogenized with 30 mL of 0.1 M NaOH in 3.5% NaCl and incubated at 60°C for 90 minutes before being plated. The dilutions were plated on a microplate in triplicate along with the samples. The dye was diluted with ddH_2O before being plated with the samples. The plate was incubated at 37°C and read using Gen 3.5 software. The protein concentration of the ground chicken and protein isolate was determined by a 1g comparison (Bradford, 1976).

3.5 Edible Coating Preparation

After protein content is determined using the Bradford method, the isolate is weighed in a beaker and homogenized with 1:3 ddH_2O (w: v). Glycerol was added at 0.4% (w/w) of protein as a plasticizer. The mixture was gently stirred for 30 minutes as the pH was adjusted with 10 N NaOH to 11 and with 6 N hydrochloric acid to 7.0. The solution was filtered through two layers of cheese cloth to remove un-dissolved debris. The coating was refrigerated for up to 12 hours before use.

3.6 Batter Preparation

The following describes the batter preparation for the commercial batter, the corn starch batter, and the sweet potato starch batter.

3.6.1 Commercial batter

Louisiana Chicken Fry Batter Mix (Baton Rouge, LA) was prepared as described on the instructions with a modification. One hundred grams of the batter was mixed with 145 mL of ddH_2O and breaded with the dry batter mix (wheat flour, corn flour, corn meal, monosodium glutamate (MSG), spices).

3.6.2 Corn starch batter

The batter consisted of 48.75% (w/w) wheat flour (King Arthur White Whole Wheat Flour, Norwich, VT), 48.75% corn starch (Argo Cornstarch, Memphis, TN), 1.0% HPMC (Methocel E15 Premium LV Hydroxypropyl Methylcellulose, Midland, MI), 1.0% salt (Morton Salt, Chicago, IL), 0.5% baking powder (Rumford Aluminum-Free Baking Powder, Terre Haute, IN) and 145 mL cold, deionized water. The batter was standardized based on viscosity, using a modified Stein Cup method. A 4-in diameter funnel was used in place of the Stein Cup. After the funnel was filled full of batter, the viscosity of the batter was considered standardized when all the running batter exited the drain hole in 11 seconds or less. The batter was made on the day of use and held no longer than 12 hours.

3.6.3 Sweet potato starch batter

The batter consisted of 48.75% (w/w) wheat flour (King Arthur White Whole Wheat Flour, Norwich, VT), 48.75% sweet potato starch (Wako Pure Chemical Industry, Richmond, VA), 1.0% HPMC (Methocel E15 Premium LV Hydroxypropyl Methylcellulose, Midland, MI), 1.0% salt (Morton Salt, Chicago, IL), 0.5% baking powder (Rumford Aluminum-Free Baking Powder, Terre Haute, IN) and 145 mL cold, deionized water. The batter was standardized based on viscosity, using a modified Stein Cup method. A 4-in diameter funnel was used in place of the Stein Cup. After the funnel was filled full of batter, the viscosity of the batter was considered standardized when all the running batter exited the drain hole in 11 seconds or less. The batter was made on the day of use and held no longer than 12 hours.

3.6.4 Breading

Plain bread crumbs (Progresso, Minneapolis, MN) were used to bread the samples. The particle size of the bread crumbs was less than 2 mm.

3.7 Frying

Chicken breast samples (10 ± 1g) were cut as uniformly as possible and refrigerated until the batter was prepared. Each sample was pre-dusted with all-purpose flour (Great Value, Bentonville, AR), followed by the edible coating and/or batter. The final step was breading, with the sample layered on top of the bread crumbs and more bread crumbs sprinkled on top of the sample. The samples were tapped to adhere the breading to the batter. The chicken breast samples were fried at 177° C in canola oil (Wesson Pure, Conagra, Chicago, IL) using the Presto® Dual ProFry/1800W (National Presto Industries Inc., WI., U.S.) for 3 minutes. The chicken was removed from the oil when 74° C was obtained and allowed to drip for a few seconds before using for physicochemical tests. The use of the same frying oil was limited to 5 hours for consistency.

Objective 2: The following evaluations were performed to examine the effects of the edible coating on the quality attributes of the fried chicken breast as well as compare batter formulation samples.

3.8 Physicochemical Analysis

3.8.1 Frying yield

The frying yield was measured immediately after frying. A higher frying yield, due to the edible coating and batter ingredients, can help decrease the coating loss and reduce degradation of the frying oil, improving costs (Maskat, Yip, & Mahali, 2005). The equation for frying yield is listed as follows:

$$\text{Frying yield (\%)} = \frac{\text{weight of the sample after frying (g)}}{\text{weight of the sample before frying (g)}} \times 100\%$$

3.8.2 Color evaluation

Color measurements were taken using a Minolta Chroma Meter CR-400 colorimeter (Minolta Camera Co. Ltd., Japan). The colorimeter was calibrated with a white standard plate. Color evaluation (L^*, a^*, and b^*) was measured on the surface of the chicken samples and expressed as the mean and standard deviation.

3.8.3 Puncture test

The texture of each sample was analyzed using the puncture test. The textural properties were measured utilizing a puncture probe (2 mm. dia., 25 mm long) with the texture analyzer (Model TA-XT2, Texture Technologies Corp., Scarsdale, NY). A 90-mm/min. cycle was observed. The peak force at first compression was measured on each side.

3.8.4 pH

Fried chicken breast samples (5g) were homogenized with 20 mL of ddH_2O in a 50 mL centrifuge tube for 2 minutes. The pH was determined using a hand-held pH meter, which was calibrated at 4.0, 7.0, and 10.0.

3.8.5 Proximate composition

The proximate composition was determined for both corn starch and sweet potato starch battered samples. Proximate composition includes fat content, fat uptake, and moisture content. The moisture content of each sample was determined by placing a 1-3g sample in the vacuum oven. The sample was weighed on Whatmann paper secured with a paper clip in a crucible. The vacuum oven was set to 100° C for 4 hours. The samples were left to dry and later moved to the desiccator for cool down (AOAC, 2010). The following equation was used to calculate the moisture content.

$$\text{Moisture content (\%)}= \frac{\text{weight of sample after drying (g)} - \text{weight of sample before drying (g)}}{\text{Weight of sample before drying (g)}} \times 100$$

Fat content was determined for all samples and was used as the original amount of fat obtained in the chicken breast due to frying. The formula below was used to calculate fat content.

$$\text{Fat content (\%)} = \frac{\text{Weight of sample after frying (g)-weight of sample before frying (g)}}{\text{weight of sample before drying (g)}} \times 100$$

Fat uptake of all fried samples and a raw sample for each treatment was determined using the Soxhlet method. The dried samples in the desiccator were processed using the Soxhlet extraction for 6 hours. Afterwards, the samples were re-dried for 30 minutes to evaporate the petroleum ether. Fat uptake was calculated using the equation below.

$$\text{Fat uptake (\%)} = \frac{\text{Fat content of sample after frying (g)} - \text{Fat content of sample before frying(g)}}{\text{Fat content before frying(g)}} \times 100$$

3.8.6 Sensory evaluation

A sensory evaluation was conducted after IRB (Institutional Review Board) approval was obtained for the survey. Seven participants overall volunteered to evaluate the quality of the fried chicken breast samples using a survey. The participants evaluated the appearance, texture, odor, and color on a 9-point hedonic scale based on degree of preference. Choices ranged from 1-dislike extremely to 9-like extremely. The evaluation was conducted on two different days with each set of samples (i.e. corn starch and sweet potato starch). Each sample was labeled with a randomized 3-digit code to prevent bias. Participants came at arranged times and were provided all the necessary materials in a white lighted space and no distractions. Coffee beans were provided to clear the nostrils between samples. The approved consent form and survey are attached in the Appendix.

3.9 Statistical Analysis

In this study, one-way analysis of variance was used to compare sample results. All experiments were completed in triplicate. For every experiment, the mean and variance were obtained using SAS Statistical Package (Version 16.0, SAS Institute, Cary, North Carolina, USA). All samples were analyzed for color, texture, pH, moisture content, fat content, ash, and sensory attributes. Tukey’s test was used to determine the difference in the mean values among all treatments.

CHAPTER 4

Results

4.1 Deep-Fried Chicken Breast Samples with Corn Starch Batter and Edible Coating

The objective of this study was to reduce the fat uptake in deep-fried chicken breast samples using an edible coating and batter modification. The corn starch and sweet potato samples were analyzed through various physicochemical analysis-frying yield, color, texture, and pH to examine the quality attributes of corn starch battered samples versus sweet potato starch battered samples.

4.1.1 Proximate composition

Table 3 depicts the fat content, fat uptake, and moisture content of the corn starch battered samples.

Table 3

Proximate Composition of Corn Starch Battered Samples

Treatment Groups						
(%)	CS CN	CB	CS	CS 5%	CS 10 %	CS 15%
Fat content	8.83 ± 0.99^{a}	7.51 ± 0.44^{a}	8.77 ± 0.13^{a}	4.95 ± 0.99^{b}	4.70 ± 0.10^{b}	4.39 ± 0.68^{b}
Fat uptake	5.08 ± 0.99^{a}	3.76 ± 0.44^{a}	5.01 ± 0.13^{a}	1.15 ± 0.99^{b}	0.90 ± 0.10^{b}	0.59 ± 0.68^{b}
Moisture Content	47.35 ± 3.31^{a}	50.02 ± 1.78^{a}	48.34 ± 3.50^{a}	51.81 ± 1.14^{a}	52.51 ± 2.46^{a}	52.18 ± 2.66^{a}

Note. The data are presented as mean values ± standard deviation (n=3). Different letters within the same row indicates significant differences (Tukey's Test, $p<0.05$) between mean values. Treatment groups are shown in Table 1.

Fat accounted for 4-9% content in each treatment sample. The fat uptake indicates the difference between the fat content of the samples and the reduction due to the edible coating and corn starch batter. The values did not change for the control and commercial battered sample as they did not contain edible coating or corn starch batter. There was a significant reduction ($p < 0.05$) in the fat uptake, as the fat uptake decreased from 5% to 0.5% among all treatments. There was a significant difference between the corn starch battered samples (CS, CS 5%, CS 10%, CS 15%).

Moisture content increased among the edible coated samples from 50-52.5% compared to the control. Moisture content increased in CB, with an overall increase in the edible coated treatments (CS 5%, CS 10%, CS 15%). There was no significant difference ($p > 0.05$) among all treatment groups.

4.1.2 pH values

Figure 1 depicts the pH values of the corn starch battered samples. pH values remained consistent among all samples ranging between 6.1-6.4. The pH increased in the edible coated treatments (CS 10%-CS 15%). There was no significant difference ($p > 0.05$) among CS CN, CB, CS, and CS 5%. There was also no significant difference between CS 10% and CS 15%. Figure 1 is shown below.

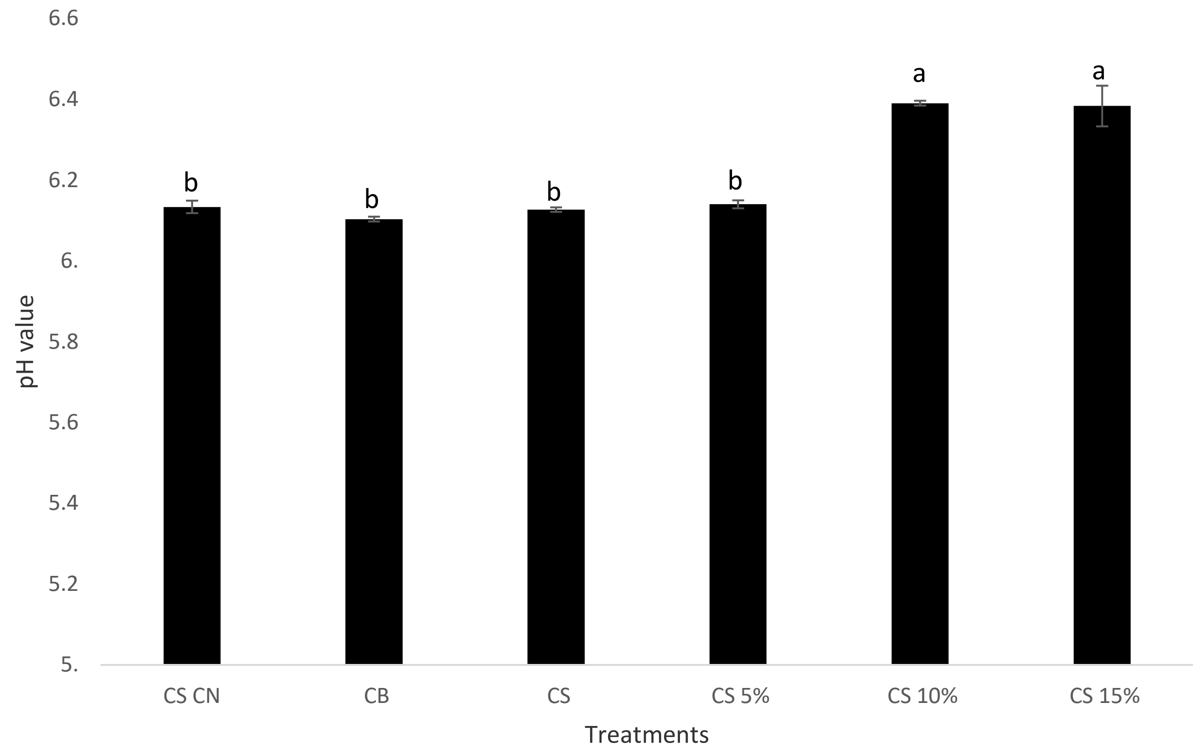

Figure 1. pH values of deep-fat fried chicken breast samples with corn starch batter. Data is given as mean values ± standard deviation (n=3). The letters on the top of data bars indicate significant differences (Tukey's Test, p<0.05) between mean values. Treatment groups are shown in Table 1.

4.1.3 Texture analysis

Texture was analyzed by the puncture force test, which indicates the tooth action in food mastication at 15% force in Newtons (N). Table 4 below shows the texture results for the corn starch battered samples. The puncture force varied greatly among the treatments. There was a significant difference ($p < 0.05$) between the corn starch battered samples, the commercial battered sample (CB), and the control (CS CN).

Table 4

Texture Analysis of Corn Starch Battered Samples

Treatment Groups						
(N)	CS CN	CB	CS	CS 5%	CS 10%	CS 15%
Puncture Force	12.61± 3.52^c	105.40± 9.95^a	70.33±9.31^b	75.91± 9.72^b	9.14± 2.56^c	5.44± 1.35^c

4.1.4 Color determination

The color values (L*, a* and b*) were evaluated for the various cornstarch batter treatments. L* values range from darkness (i.e., 0) to lightness (i.e., 100). The a* values measure redness (+60) to greenness (-60) values. The b* scale is a measure of the yellowness (positive values) to blueness (negative values).

Table 5 depicts the color values for all corn starch batter treatments. The L* values for the corn starch value treatments ranged from 48-50.5, indicating a range closer to lightness. There was a significant difference ($p < 0.05$) among L* values. The a* values increased with a higher concentration of edible coating. There was a significant difference ($p < 0.05$) among the corn starch battered samples, and a significant difference between the control and commercial batter. All treatment groups had positive b* values, indicating yellowness. There was a significant difference ($p < 0.05$) among the corn starch battered samples (CS, CS 5%, CS 10%, CS 15%). These same values also decreased indicating a shift toward blueness. There was a significant difference between the control (CS CN) and the commercial battered sample. There was a significant difference ($p < 0.05$) between the control and all other samples.

Table 5

Color Properties of Deep-Fat Fried Corn Starch Battered Chicken Breast Samples

Treatment Groups						
	CS CN	CB	CS	CS 5%	CS 10%	CS 15%
L*	56.32 ± 2.33^{a}	57.94 ± 1.05^{a}	50.46 ±0.71^{b}	50.59 ± 2.35^{b}	48.00 ± 0.80^{b}	49.19 ± 1.74^{b}
a*	5.52 ± 0.59^{c}	9.51 ± 0.43^{ba}	11.41 ± 0.13^{a}	8.1 ± 1.64^{bc}	10.59 ± 0.35^{ba}	9.13 ± 1.61^{ba}
b*	18.78 ± 1.47^{b}	24.91 ± 0.54^{a}	13.7 ± 0.22^{c}	10.86 ± 1.96^{dc}	12.96 ± 1.07^{dc}	9.28 ± 2.66^{d}

Note. The data are presented as mean values ± standard deviation (n=3). Different letters within the same row indicate significant differences (Tukey's Test, $p<0.05$) between mean values. Treatment groups are shown in Table 1.

4.1.5 Frying yield

The frying yield of the corn starch battered samples is indicated in Table 5 below. The frying yield increased among all treatments compared to the control. The frying yield decreased slightly for the 10% edible coating treatment.

Table 6

Frying Yield of Corn Starch Battered Samples

Treatment Groups						
(%)	CS CN	CB	CS	CS 5%	CS 10%	CS 15%
Frying Yield	57.73 ± 0.66^{b}	82.18 ± 0.19^{a}	84.45 ± 0.42^{a}	84.12 ± 0.22^{a}	81.30 ± 0.71^{a}	84.46 ± 0.45^{a}

4.1.6 Sensory evaluation

Sensory evaluation was conducted to analyze the quality attributes of the battered and coated samples in comparison to the control and commercial battered samples. An average score for each attribute (appearance, texture, color, and odor) was obtained for each treatment. A 9-point hedonic scale was used to indicate degree of likeness, with 1 being dislike extremely and 9 being like extremely well. CS 5% had the highest overall sensory scores among all attributes. All corn starch battered samples had higher attributes scores than both the control (CS CN) and commercial batter samples (CB), indicating an equal likeability among consumers. In addition, the sample with the highest attribute scores was the 5% edible coated sample. There was a significant difference ($p < 0.05$) for CS CN and CS 10% and CS 15% corn battered samples. Figure 2 displays the results below.

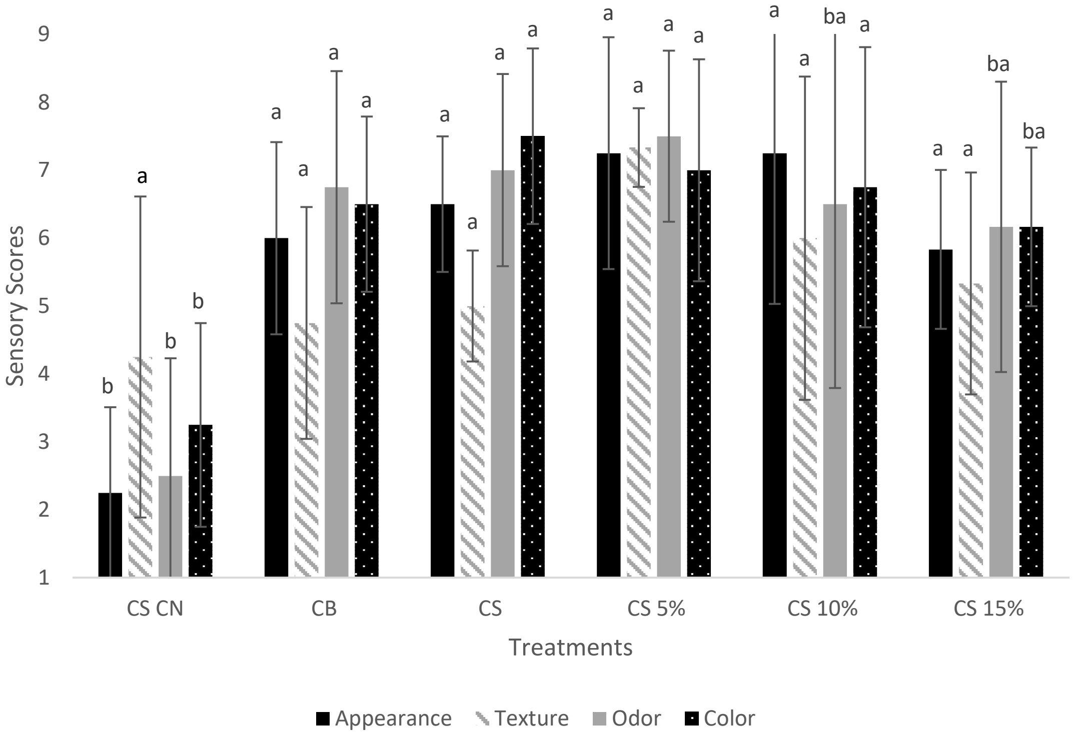

Figure 2. Sensory scores of deep-fat fried chicken breast samples with corn starch batter. Data are given as mean values (n=4). The letters on the top of data bars indicate significant differences (Tukey's Test, p<0.05) between mean values. Treatment groups are shown in Table 1.

4.2 Deep-Fried Chicken Breast Samples with Sweet Potato Batter and Edible Coating

4.2.1 Proximate composition

Table 7 depicts the fat content, fat uptake, and moisture content of the sweet potato starch battered samples. Fat accounted for 4-9% content in each treatment sample.

Table 7

Proximate Composition of Sweet Potato Starch Battered Samples

Treatment Groups						
(%)	SP CN	CB	SP	SP 5%	SP 10%	SP 15%
Fat content	8.83±0.01^{a}	7.51± 0.44^{ba}	5.74±0.66^{bac}	5.17±2.48^{bc}	4.98±1.26^{bc}	3.79±0.67^{c}
Fat uptake	5.03± 0.99^{a}	3.71±0.44^{ba}	1.94±0.66^{bac}	1.37± 2.48^{bc}	1.18± 1.26^{bc}	0.00 ± 0.67^{c}
Moisture content	47.35±3.31^{c}	50.02±1.78^{bc}	56.96±1.22^{ba}	43.22± 2.02^{c}	55.20± 1.12^{ba}	61.18± 4.20^{a}

The fat uptake values did not change for the control and commercial battered sample as they did not contain edible coating or sweet potato starch batter. There was a significant reduction in the fat uptake, as the fat uptake decreased from 5% to 0% among all treatments. There was a significant difference ($p < 0.05$) between the sweet potato starch battered samples (SP, SP 5%, SP 10%, SP 15%). Moisture content increased among the edible coated samples from 43-61%. Moisture content increased in SP, with an overall increase in the edible coated treatments (SP 5%, SP 10%, SP 15%). There were significant differences ($p < 0.05$) among all sweet potato starch battered treatment groups. There was no significant difference between SP and SP 10%.

4.2.2 pH values

Figure 3 depicts the pH values of the sweet potato starch battered samples. pH values remained consistent among all samples ranging between 6.0-6.6. The pH decreased in the edible coated treatments (SP 5%, SP 10%, SP 15%). There was no significant difference among SP CN-CB and SP 10%- SP 15%.

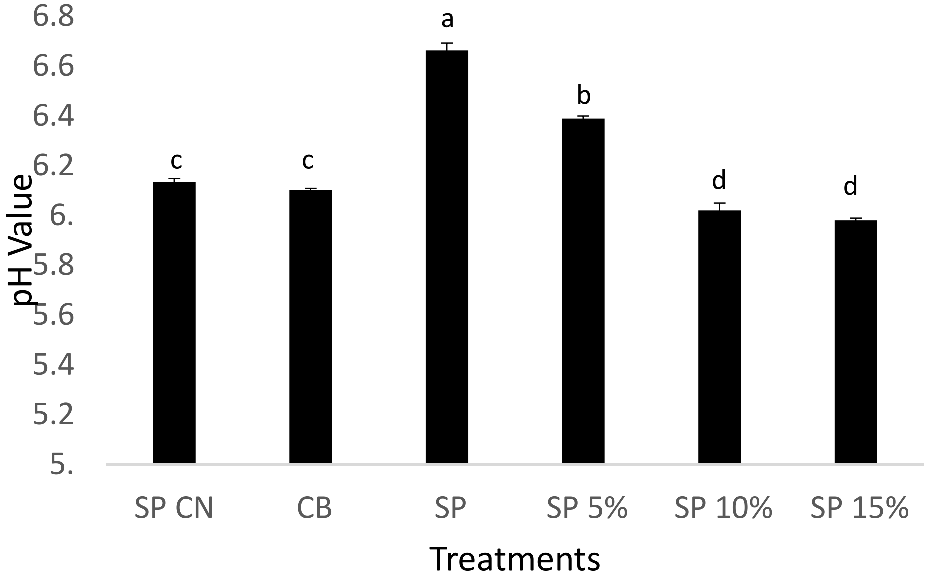

Figure 3. pH values of deep-fat fried chicken breast samples with sweet potato starch batter. Data are given as mean values ± standard deviation (n=3). The letters on the top of data bars indicate significant differences (Tukey's Test, p<0.05) between mean values. Treatment groups are shown in Table 2.

4.2.3 Texture analysis

Texture was analyzed by the puncture force test, which indicates the tooth action in food mastication at 15% force in Newtons (N). Table 8 below displays the results. The force of mastication decreased among the treatments, indicating a change in the thickness of the batter, breading, and coating. The commercial batter had the highest force of mastication and was significantly different ($p < 0.05$) than the other treatments. There was a significant difference ($p < 0.05$) between CB and the other treatments.

Table 8

Texture Profile of Sweet Potato Starch Samples

	Treatment Groups					
(N)	SP CN	CB	SP	SP 5%	SP 10%	SP 15%
Puncture Force	12.61±3.52^b	105.64± 9.95^a	3.7± 0.23^b	3.45±0.35^b	3.14±0.14^b	3.05±0.02^b

4.2.4 Color determination

The color values (L*, a* and b*) were evaluated for the various sweet potato starch batter treatments. L* values range from darkness (i.e., 0) to lightness (i.e., 100). The a* values measure redness (+60) to greenness (-60) values. The b* scale is a measure of the yellowness (positive values) to blueness (negative values).

Table 6 depicts the color values for all sweet potato batter treatments. The L* values ranged from 39.5-56.3, indicating a diverse range of darkness to lightness. There was no significant difference ($p > 0.05$) between CB and SP 10%, as well, as SP and SP 15%. The a* values increased with a higher concentration of edible coating. There was no significant difference ($p > 0.05$) between SP 10% and SP 15% (sweet potato starch battered). There was a significant difference ($p < 0.05$) among the control (SP CN), commercial batter (CB), and sweet potato starch battered samples (SP, SP 5%, SP 10%, SP 15%). All treatment groups had positive b* values, indicating yellowness. There was no significant difference ($p > 0.05$) between the sweet potato starch battered samples (SP 10%, SP 15%). These same values also decreased indicating a shift toward blueness. There was no significant difference ($p > 0.05$) between the control (SP CN) and the commercial battered sample. There was a significant difference ($p < 0.05$) between the edible coated samples (SP 5%, SP 10%, SP 15%).

Table 9

Color Properties of Deep-Fat Fried Sweet Potato Starch Battered Chicken Breast Samples

Treatment Groups						
	SP CN	CB	SP	SP 5%	SP 10%	SP 15%
L*	56.32 ± 2.33^{a}	52.38 ± 7.09^{a}	45.33 ± 2.30^{c}	39.53 ± 3.73^{d}	52.49 ± 1.07^{b}	42.32 ± 1.48^{d}
a*	$5.52\pm.59^{dc}$	8.79 ± 2.10^{ba}	10.58 ± 0.42^{a}	2.85 ± 0.23^{d}	6.62 ± 0.64^{bc}	7.16 ± 1.49^{bc}
b*	18.78 ± 1.47^{a}	22.14 ± 6.56^{a}	10.85 ± 0.23^{b}	1.83 ± 0.39^{c}	6.37 ± 0.33^{cb}	5.29 ± 0.82^{cb}

Note. The data are presented as mean values ± standard deviation (n=3). Different letters within the same row indicate significant differences (Tukey's Test, $p<0.05$) between mean values. Treatment groups are shown in Table 1.

4.2.5 Frying yield

The frying yield of the sweet potato starch battered samples is indicated in Table 7 below. The frying yield increased in CB and SP. The yield also increased as the concentration of the edible coating increased (SP 10% and SP 15%, respectively).

Table 10

Frying Yield of Sweet Potato Starch Battered Samples

Treatment Groups						
(%)	SP CN	CB	SP	SP 5%	SP 10%	SP 15%
Frying Yield	57.73 ± 0.66^{b}	81.55 ± 0.19^{a}	82.04 ± 0.41^{a}	84.67 ±0.19^{a}	84.58 ±0.06^{a}	87.17 ± 0.40^{a}

4.2.6 Sensory evaluation

Sensory evaluation was conducted to analyze the quality attributes of the battered and coated samples in comparison to the control and commercial battered samples. An average score for each attribute (appearance, texture, color, and odor) was obtained for each treatment. A 9-point hedonic scale was used to indicate degree of likeness, with 1 being dislike extremely and 9 being like extremely well. SP had the highest sensory scores among all attributes. All the sweet potato battered samples had lower sensory scores than the commercial batter, indicating a lower likeability among consumers. In addition, the sample with the highest attribute scores was the sweet potato starch sample with no edible coating. There was a significant difference ($p < 0.05$) for the control (SP CN) and sweet potato battered sample no coating (SP). There was no significant difference ($p > 0.05$) between the commercial battered sample (CB) and the 15% sweet potato coated sample (SP 15%). Figure 4 displays the results below.

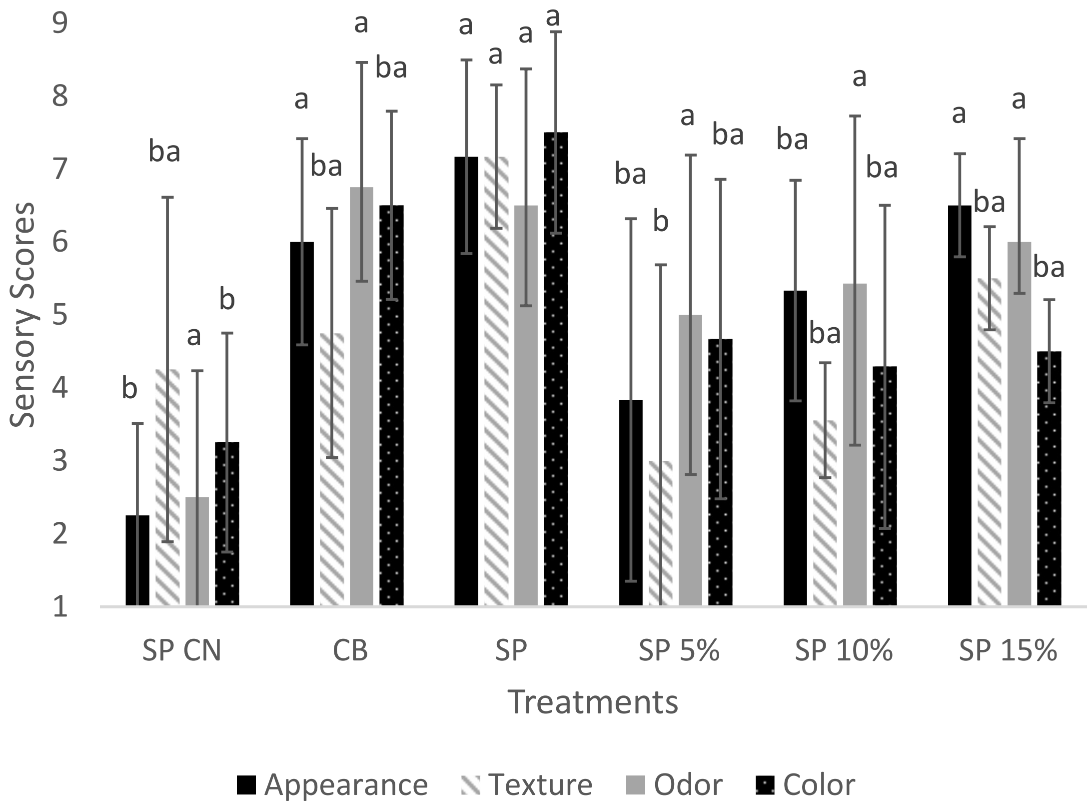

Figure 4. Sensory scores of deep-fat fried chicken breast samples with sweet potato starch batter. Data are given as mean values (n=7). The letters on the top of data bars indicate significant differences (Tukey's Test, p<0.05) between mean values. Treatment groups are shown in Table 2.

CHAPTER 5

Discussion and Future Research

The following chapter contains the evaluation of the results for corn starch and sweet potato starch battering systems, including the analysis of fat uptake, moisture content, pH, color properties, frying yield, and the sensory evaluation. Each hypothesis was addressed according to the objectives. The results of this study were compared with similar research in the same discipline for further analysis.

Lowering the amount of fat in foods is deemed important because there is an excess amount of fat consumed in the American diet. According to Simoes, Byers, Coates, Serdula, Mokdad, and Heath (1995), fried chicken and other fatty foods accounted for 65% of dietary fat in a survey among American adults. Increased consumption of fried, high fat foods increases the risk of several chronic diseases, including type 2 diabetes, hypertension, cardiovascular disease, and many cancers (Satia & Galanko, 2007).

Hypothesis 1: If the chicken protein based edible coating is effective, there will be a reduction in the fat uptake.

Fat content and fat uptake were observed for all corn starch battered and sweet potato starch battered samples. Among the corn starch battered samples, the 5% coated sample had the lowest fat content, and the 15% coated sample had the lowest fat uptake. Among the sweet potato starch battered samples, the 15% coated sample had the lowest fat content and the lowest fat uptake, indicating the edible coating does contribute to the reduced oil absorption. The sweet potato starch and protein coating contributed to reduced fat uptake. According to the results stated above, the hypothesis can be accepted. The increased reduction in fat uptake of the sweet potato starch samples could be due to sweet potato starch having an increased water holding capacity which contributes to its protective barrier (Babu, Parimalavalli, Jagannadham, Rao, & Gaur, 2016). Also, the protein coating formed from myofibrillar proteins create a gel-like structure due to the arrangement of collagen. This allows enough strength to create a protective barrier (Ananey-Obiri et al., 2018).

Similar studies have examined that both edible coating and batter containing hydroxypropyl methylcellulose (HPMC) have reduced fat uptake (Albert & Mittal, 2002; Malikarjunan, Chinnan, Balasubramaniam, & Phillips, 1997; Moyano & Pedreschi, 2006; Garcia, Ferrero, Bertola, & Martino, 2002). The fat content in the sample can vary due to the cut of meat used for the sample preparation. All the chicken breasts were fresh, but did not have the same amount of fat, as some meat contained more fat than others. This is mostly attributed to the way the chicken was raised. According to the Agricultural and Renewable Resources Board (1976), when chickens are fed a low protein feed, they increase their voluntary energy consumption and deposit more body fat. This means that even though chickens may have been packaged from the same farm, there is no guarantee the chickens will be fed the same diet and obtain an equal body mass.

Moisture content is also influenced by fat uptake. Decreasing fat uptake correlates with a higher moisture content, due to the added ingredients of the batter that increase the surface tension of the product. Increased surface tension reduces the pore space susceptible to moisture loss due to the created barrier (Adedeji, 2010). The highest moisture content was observed in both the 10% corn starch coated sample (CS 10%) and the 15% sweet potato starch coated sample (SP 15%), indicating that the coating also adds value to the sensory attributes. The corn starch sample values were not significantly different ($p > 0.05$) from the control (CS CN) or commercial batter (CB), indicating that the corn starch batter did not influence the moisture content. All the sweet potato starch sample values were significantly different ($p < 0.05$) from the control (SP CN) and commercial batter (CB), except the 5% coated sample (SP 5%). The increased moisture content of the sweet potato starch samples could be due to the lower amylose content of the sweet potato starch, as the starch granules readily interact with water (Singh & Kaur, 2004; Horstmann, Lynch, & Arendt, 2017). This allows gelatinization to occur more quickly and prevent the loss of water.

Other studies have shown variation in reducing moisture loss due to an edible coating or batter system. For instance, Dragich & Krochta (2010) showed a reduced moisture loss with the use of a 10% whey protein isolate coating. However, Mah, Price, and Brannon (2008) showed that there was a reduction in oil uptake on a cracker meal coated sample with no edible coating, indicating that pH could play a role in fat uptake.

Hypothesis 2: If the corn starch in the batter is replaced with sweet potato starch, the deep-fat fried chicken breast will have better quality attributes.

According to the hypothesis, the quality attributes being evaluated are pH, color, texture, frying yield, and the sensory evaluation. The pH values of corn starch and sweet potato starch battered samples are compared below, followed by texture, sensory evaluation, color, and frying yield.

The higher pH gels (pH 8.0) had a higher fat content and larger pores than the lower pH gels (pH 2.0 and 3.0). The pH values of the corn starch battered samples varied slightly between 6.2-6.4, while the pH values of the sweet potato starch battered samples (6.6) varied significantly from the control (6.0). pH values influence the gelation properties of the edible coating, as the isoelectric point (5.5) for chicken must be reached to assure proper gelation and an adequate barrier for the chicken during frying. While the higher pH showed larger pores in the study by Mah, Price, and Brannon (2008) and a higher oil absorption, the pore structure of the samples in this could not be determined. However, the combination of the use of an edible coating and starch batter created a solid barrier against oil absorption. In addition, the use of corn starch versus sweet potato starch impacted the gelation and oil absorption. Corn starch has a higher rate of reduced functionality due to gelatinization loss and its amylose content (Skibsted, Risbo, & Andersen, 2010, in screenshots) while sweet potato starch has a higher rate of syneresis, a desirable texture, and enhanced water-binding capacity (Nwokocha et. al., 2014).

The texture results examined the peak force at first bite using the puncture test. A higher peak force can indicate an increased moisture loss (Lima & Singh, 2000). The highest puncture force among all treatments was observed for the commercial battered sample (105 N). The amount of force decreased among the corn starch and the sweet potato starch samples, indicating a decreased moisture loss. In addition, the crust structure was observed to be harder in sweet potato samples, indicating the occurrence of gelation and an oil absorption barrier. The crust formation and fracture are indicative of a palatable fried chicken breast sample, as puncture force correlates to crispiness or hardness (Chen & Opara, 2013). The edible coating contributed to the texture, as a moisture barrier developed that contributed to the samples' hardness.

Sensory evaluation was completed to compare the quality attributes of the raw chicken breast and the commercial battered chicken breast to the sweet potato starch and corn starch battered samples (n=4). The quality attributes evaluated included appearance, color, odor, and texture and were measured on a 9-point hedonic scale. Among the corn starch battered samples, the 5% coated treatment had the most favorable scores, indicating consumer acceptability. Among the sweet potato starch battered samples, the 5% coated treatment had the most favorable scores. Among all treatments, the corn starch battered samples had the most favorable scores. This could be due to the darker color produced by the sweet potato starch when fried as well as its perceived hardness as a result of the coating's gelation which has larger granules present in the sweet potato starch. Upon reviewing the literature, most sensory evaluations observed sweet potato starch in grain products such as noodles and bread and was deemed favorable (Greene & Bovell-Benjamin, 2004; Ibitoye, Afolabi, Otegbayo, & Akintola, 2013). This sensory evaluation is a separate approach among fried products.

As color is of value to sensory attributes, color was examined during this study. Among the corn starch battered samples, the color was lighter for all treatments compared to the controls. In addition, all a* and b* values were positive, indicating redness and yellowness. In contrast, among the sweet potato samples, the color was darker for all treatments. Specifically, the a* and b* values were closer to green and blue. This could be due to darker samples upon frying. According Kitahara, Nakamura, Otani, Hamada, Nakayachi, & Takahata (2017), low amylose content in sweet potato starch can create larger granules and affect the color and taste of its products negatively. The processability and quality of the sweet potato were both affected by the larger granules. Even though the edible coating was white in color, the order of processing i.e. pre-dusting, edible coating, battering, determined the final color of the sample, hence the darkness and reddish colored sample.

The frying yield was analyzed as an important quality in fried food production. Frying yield is influenced by batter pickup as the viscosity of the batter determines how well it acts as a protective coating. A higher viscosity correlates to a higher frying yield and decreased oil uptake. The frying yield among all the corn starch battered samples and the sweet potato starch battered samples was higher than the controls. In addition, the sweet potato samples had a higher frying yield than all the other samples, indicating a more gelatinous coating and increased viscosity.

In conclusion, fat uptake reduction in the samples occurred due to the use of an edible coating. In terms of fat uptake reduction, there was no significant difference among the cornstarch battered samples ($p > 0.05$). There was no significant difference among the 5% and 10% sweet potato samples (SP 5%, SP 10%), but the 15% coated sweet potato sample (SP 15%) exhibited the highest moisture content, frying yield, and lowest fat uptake and fat content among all the treatments, meeting hypothesis 1. This was due to the performance of the HPMC which was more favorable in the sweet potato starch batter, which coagulates and forms a protective layer or barrier between the batter, breading, and the meat. Among the quality attributes as addressed in hypothesis 2, sweet potato starch battered samples did not have better quality attributes than corn starch. This was especially important among the texture, color, and sensory evaluation results. As stated previously this could be due to the observed color of the samples (darkish red) and crust hardness (3 N), which affected the perception of participants in the sensory evaluation.

After obtaining these results the following future research could be developed. A more in-depth sensory evaluation involving taste among at least 40 participants with the samples of the lowest fat uptake and fat content (CS 15%, SP 15%). In addition, storage and stability testing of the samples with an antimicrobial coating could reduce spoilage in its raw state (chicken breast) and the edible coating. In addition, the oil type could be varied as the color of the samples could be affected by the oil type.

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Appendix

Study Title: Fat Uptake Reduction in Deep-fat Fried Chicken Breast

Principal Investigator: Lovie Matthews

Faculty Advisor: Dr. Reza Tahergorabi

Dear Respondent,

I am inviting you to participate in a research study about fried food quality. The procedure involves completing a sensory evaluation sheet that will take approximately 15 minutes. Through your participation, I hope to understand the effect of edible coating on quality attributes of fried chicken. You must be at least 18 years old to participate. Your participation is voluntary and there is no penalty if you do not participate.

To participate, I would like for you to evaluate the appearance, color and odor of the fried samples. Texture (hardness) of the samples could be tested visually and by touching.

There are no risks associated with your participation though you are not being asked to taste the chicken.

This project has been approved by the Institutional Review Board (IRB) at North Carolina A&T State University.

By completing this survey, you are indicating that you at least 18 years old, have read this document, have had any questions answered, and voluntarily agree to take part in this research study.

Sincerely,

SENSORY EVALUATION OF FRIED SAMPLES

Panelist Number: **Date:**

Produce Name: Fried Chicken Breast

INSTRUCTIONS

Please use the scale below to express your response on the coded samples. Choose the number that best matches your response.

Degree of Preference	
9	Like Extremely
8	Like Very Much
7	Like Moderately
6	Like Slightly
5	Neither like nor Dislike
4	Dislike Slightly
3	Dislike Moderately
2	Dislike Very Much
1	Dislike Extremely

Sample code	Description	1	2	3	4	5	6	7	8	9
	Appearance									
	Texture									
	Odor									
	Color									
	Appearance									
	Texture									
	Odor									
	Color									
	Appearance									
	Texture									
	Odor									
	Color									