Effect of Modified Starch on Bake-Only Chicken Nuggets

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Effect of Modified Starch on Bake-Only Chicken Nuggets
Effect of Modified Starch on Bake-Only Chicken Nuggets

A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science in Food Science

by

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ABSTRACT

The food industry has become increasingly focused on healthier items. Fried foods especially are actively pursuing non-fried alternatives to attract health conscience consumers. This study investigated the bake-only chicken nugget formulation in attempts to provide characteristics of fried items. Starch was hydrolyzed by amyloglucosidase to create a porous structure that had the ability to absorb oil. Oil was plated into the enzyme-treated starch and blended into nugget formulation, and the coated nuggets were steam-baked until fully cooked. The enzyme-treated starches showed a decrease in gelatinization range and pasting viscosities for all starch types. The addition of oil-plated enzyme modified starch improved crispness and mouth-coating characteristics and was perceived as comparable to industry prepared partially fried nuggets. Oxidized starches were also prepared from various starches in batter and breading formulations to increase the adhesion and crispness of steam-baked chicken nuggets. Differences were noted in peak force measured by a texture analyzer, acoustic reading, and hardness and crispiness by a trained panel. However, the oxidized starch prepared from various sources did not added desirable characteristics over the control evaluated by the sensory panel. Overall the addition of oil-plated enzyme modified starch into a bake-only nugget formulation aided in a positive impact on texture and mouthcoat.
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1. Enzyme-Modified Starch as an Oil Delivery System for Bake-Only Chicken Nuggets. Journal of Food Science.

CHAPTER 1

INTRODUCTION

Recently the subject of obesity has become an increasingly problematic topic. In the United States alone, the percentage of overweight adults (age 20-74) has increased from 15.0% to 32.9% in the last twenty-three years (CDC 2007). This increase however is not limited to adults alone. Childhood obesity has climbed significantly; 17.4% of all children ages 12-19 and 18.8% of children within 6-11 years are obese. Even at age 2-5 years, 13.9% of children are classified as obese (CDC 2007). These statistics are raising much needed concern about the health and wellness of our nation. While many lifestyle choices are targeted, one of the main areas of concern is food.

Fast food has been continuously targeted for causing obesity. However, despite this claim, the numbers entering a fast food establishment has sustained due to the convenience factor. Nevertheless, consumers have begun to demand more “healthy menu options”. This demand has shown to be desirable; salads, fruit, and low-fat options are now offered on all national chain menus. However most of these items are targeted towards adults.

Children also need to be offered healthier options. These options do not have to be drastic, but instead could simply be “healthier” versions of familiar products. Chicken nuggets are one of the most popular meals for kids; however it is high in fat. According to McDonald’s menu, a 6-piece chicken McNugget has 250 calories with 130 calories from fat. The frying process is the primary contributor of the nuggets high fat content. Therefore the nutritional value of chicken nuggets can be improved by eliminating the frying process.

Frying imparts several critical product functionalities. Frying sets a coating to a substrate, develops texture and color, and provides mouth-feel and flavor. These are all desirable
characteristics that consumers enjoy regarding fried food, however they are often lost when nuggets are baked. The food industry has yet to duplicate all of the unique characteristics of fried chicken nuggets with a baking process.

Despite the few bake-only chicken nuggets that exist today, the coating on these nuggets still needs work to provide desired characteristics. Because the batter formula is the key aspect of the chicken nuggets, it is hypothesized that the batter formula can be improved by incorporating starch derivatives to better imitate the texture and mouth-feel of the fried version. Texture and adhesion are the two main characteristics that must be improved for the bake-only chicken nugget. The findings from this research will provide an understanding of the contributions of starch derivatives to texture and adhesion of bake-only nuggets, and future directions to perfect the batter formula for bake-only nuggets. It is anticipated that the results will benefit the food industry by utilizing ingredients in a new and functional way and thus will give the industry a better tasting, healthier chicken nugget.

REFERENCES

Batter and Breading Ingredient Review

Chicken nuggets consist of a meat substrate with a bread-based coating. This breading system usually consists of three steps: pre-dust, batter, and breading. The pre-dust provides a means to apply more breading onto a substrate. A pre-dust is often used to aid in adhesion and moisture absorption from the substrate, thus it often contains adhesive agents like gluten, whey, and dried egg. The batter is the only hydrated component and is composed all the functional ingredients that will define the final product. For example, leavenings are added to the batter alone to create and promote air entrapment into the coating. A large amount of leavening creates a very spongy product that greatly absorbs oil in the frying process. Finally, the breader acts as a batter-coating agent and is responsible for customer eye appeal. The breader may contain a variety of bread crumbs or simply be flour based. After the application, the nugget coating is “set-into-place” via frying. Nuggets can be fully fried or partially fried (par-fried), and either frozen for later reconstitution or fully cooked via frying or oven. Despite the duration of frying (par-fried 30-90 sec or fully fried 2-4 min) the amount of oil absorbed into the coating is tremendous. The coating acts as an oil barrier during the frying process to prevent absorption into the substrate; the batter step is the key component for preventing substrate-oil interaction.

Batters function in a variety of categories; among them adhesion, all-purpose, dough, and coating are the most common batter types. Depending on the batter application and/or function, ingredients are selected to meet the desired application requirements. The most common components of batter formula include water, flour, starch, leavening agents and spices.
The base ingredient of most batters is flour. Wheat flour is the most common type utilized, however many others have also been studied. Salvador and others (2002) replaced 3 and 6% wheat flour with corn flour (w/w, db), and then used the mixture in a batter 1:1.2 (w/w) with water before applied to squid rings upon frying. It was found that batter pick-up with corn flour was not significantly different from that of a control of 100% wheat flour. Replacing wheat flour up to 6% with corn flour neither resulted in a significant difference in 0, 15, and 30-min post-fried textures.

Rice flour imparts desirable properties, such as crispy, yet light texture, which are attractive for many applications, including batters. Thus rice flour is becoming more widely used in gluten-free products or “health conscious” products. Dogan and others (2004) showed that a chicken nugget batter formulation replaced with 5% rice flour absorbed less oil, bound less water, and consequently had a lower viscosity compared with the controls. However when pregelatinized rice flour was incorporated, oil absorption increased. The process of creating pregelatinized flours or starches creates a more porous structure, resulting in a rapid influx of oil during frying (Dogan and others 2004). Because of the decrease in viscosity, the final product texture was much softer and final yield was lower than controls (Dogan and others 2004). A recent study by Jackson and others (2006) reported that baked, dry battered wheat-free formulations containing rice flour exhibited less tender texture than wheat-based fried ones. This difference however was not significant; Jackson and others (2006) stated that all samples were very tender compared to other research. When comparing fried versus baked formulations using the same coating type, there were no discernable differences in formulas between baked and fried. This study also evaluated consumer preference of rice flour verses wheat flour, baked
verses fried, and dry batter verses wet. Overall consumers preferred nuggets that were prepared with the dry batter, the rice flour-baked nugget, and the wheat-based fried nugget (Jackson and others 2006).

Soy flour, unlike wheat flour, is not typically utilized as the base component of a batter. It does, however, provide unique properties that cannot be obtained with other flours alone. The study by Dogan and others (2005) replaced wheat flour with 5% defatted soy flour in a wheat-based chicken nugget batter. Due to the high concentration of protein in soy flour and its high affinity for water, the viscosity and overall pick-up were significantly greater than all other formulas.

Corn meal

Corn meal is often used in breaded type products to create a desired organoleptic or texture sensation. The texture and taste of corn meal is very distinct and is utilized to target a specific market. Acioli-Moura and Chang (2006) studied the effects of corn meal on extruded wheat-based breading and showed that corn meal did not significantly improve the texture of the finished extruded product. Corn meal neither had an effect on substrate adhesion.

Starch

Starch is an essential ingredient for coating batter formulations, and aids in adhesion, encapsulation, and overall texture of the product. Starches are often classified by source and modification type. Corn, wheat, rice, potato and tapioca starches are the most commonly used sources for batter formulas due to availability. Native starch can be utilized in batter formulations, but viscosity must be taken into consideration; modified starch can be utilized when native may not be as effective (Salvador and others 2005). Modification via chemical,
physical and/or enzymatic means enables starch to be incorporated into many different applications by altering its solubility, water-binding capacity, texture, and time and temperature of gelatinization. Oxidation, one of the allowed chemical modifications by FDA (21 CFR Ch1), is the most common modification for batter applications. It improves binding, film forming, and stability of the coating to the substrate. Pregelatinized starch, another type of modified starch, is desirable for developing up-front viscosity for batter-to-freeze items.

Kuakpetoon and Wang (2001) studied hypochlorite-oxidized starches from different plant sources (rice, potato, corn) and evaluated the level of starch oxidation in attempt to relate molecular structure to functional aspects of the oxidized starch. Oxidation of starch mainly occurs at hydroxyl groups with conversion to carbonyl groups and then to carboxyl groups. Pasting properties were drastically altered for all starches after oxidation; nonetheless each starch displayed different properties. Oxidized corn and rice starches showed a lower pasting temperature than the unmodified ones, whereas potato starch exhibited little change in pasting temperature after oxidation by 0.8 and 2% NaOCl. Adhesion values were significantly different among starches with oxidized rice starch showing the highest adhesion value. They concluded that the extent of oxidation was affected by starch crystalline structure and amylose structure.

Altunakar and others (2004) studied various starches to determine their impact on batter formulations. Oxidized amylo maize (Crisp Film, National Starch and Chemical), corn, pregelatinized tapioca, and waxy maize were evaluated on texture, moisture, oil absorption, pick-up, cooking yield, color, and porosity of final fried nuggets. Due to its high affinity for water, pregelatinized tapioca starch had a significant impact on batter pick-up. Moisture retention was significantly higher in the pregelatinized tapioca starch batter for 3-9 min of frying time. However the starch was disintegrated and the moisture dropped below the control batter value.
after frying for 12 min. High amylose starch (amylo maize) was found to have a positive impact on final product texture. When the frying time increased, the peak force (N) to penetrate the coating increased for all starches. The peak force requiring 25% penetration of a conical probe into the fried sample was used for the crispness attribute. The increased force was attributed to the formation of a film from leached amylose after granule swelling, which restricted moisture migration and oil absorption. Waxy maize showed the lowest porosity, thus low oil pick-up, whereas corn starch had the highest porosity.

Salvador and others (2005) compared the effect of replacing 7.5% (w/w db) flour with native wheat starch and modified corn starch on batter characteristics for a frozen squid ring substrate. Texture measurement showed that the maximum peak force of the fried coating with wheat starch was smaller than the one with modified corn starch immediately after frying but no difference was observed after 15 and 30 min of frying.

Akdeniz and others (2005) combined pregelatinized tapioca starch with maltodextrin in a batter formulation to understand the effect of tapioca starch on texture attributes. At 5% direct replacement (w/w db) tapioca starch provided the crispest texture with the lowest oil absorption. Improvements in texture were also seen when replacing batter wheat flour with 3 or 5% of maltodextrin without tapioca starch. The latter maintained longer crispiness after frying when compared to the control containing no maltodextrin, but the duration of crispiness was not determined.

Acioli-Moura and Chang (2006) studied high amylose corn starch on extruded breading characteristics, and reported that high amylose corn starch (70% amylose content) had a significant positive influence on pick-up, texture and adhesiveness to the substrate. As the starch concentration increased in the formula, the maximum force to break the final product
proportionally increased. When 5-26% of high amylose starch was combined with 13-23% vital wheat gluten, the finished product showed a desirable consumer texture profile.

In a recent patented study, porous glucoamylase-modified starch displayed promising beneficial characteristics in possessing fluid-absorbing properties (Bazin and others 2004). This enzyme-modified starch can act as an encapsulating agent, carrier agent, controlled release agent and drying agent. These characteristics aid in the absorption of liquid into starch while maintaining a powder-like texture and appearance.

Hydrocolloids

Hydrocolloids, or gums, can be commercially obtained from numerous sources, and provide distinct functionalities. Although hydrocolloids can be utilized in most food products, only a few can be functionally beneficial in a coating system. Many gums have been tested in batters; but all of those batters are used in pre-fried or full fried items.

Fiszman and others (2005) compared the advantages and disadvantages of various hydrocolloids for batter applications. Traditional batter formulations (flour and water) generally have a low inherent viscosity, particularly for rice flour based batters. Therefore, hydrocolloids are often incorporated to increase the batter viscosity and/or suspended high molecular weight ingredients. However formulas may need a combination of hydrocolloids or hydrocolloids plus starch to achieve desired flow characteristics. For example oxidized starch, xanthan gum, and methylcellulose showed promising results for rice flour based breader (Mukprasirt and others 2000a; 2001). Xanthan and tragacanth gum especially have been greatly studied for providing adequate particle suspension by increasing viscosity at very low levels (0.10-0.25% w/w) (Fiszman and others 2005). Another valuable aspect of hydrocolloids is their ability to absorb
and sustain water within a batter. Therefore adding gums that will bind large amounts of water will help increase coating pick-up (Fiszman and others 2005).

Despite the versatility of hydrocolloids, certain characteristics need to be maintained when considering their use. Some gums, such as carboxymethylcellulose (CMC), are charged and thus lose functional properties in the presence of high salt concentrations. Some cellulose products such as methyl cellulose (MC) and hydroxypropyl methyl cellulose (HPMC) however are sensitive to temperature abuse (Fiszman and others 2005). Therefore it is essential to understand the processing parameters of the application before selecting the appropriate gum(s).

Another important aspect to consider is the desired final product texture. Increasing levels of MC increased moisture absorption, leading to a less crisp product; however moisture retention aided in film formation and preserved integrity. Similarly increasing xanthan gum within a batter produced a chewy bite (Fiszman and others 2005).

Hsia and others (1992) compared three hydrocolloids (guar, xanthan, and CMC) in a standard batter formulation at 0.25, 0.5, or 1.0% (w/w) concentration for chicken nugget application. Significant increases in apparent viscosity and batter pick-up were directly related to increased xanthan and guar concentrations. However, batters containing CMC at any level did not show significant differences against the control containing no gum. Flow behavior for batters containing gums increased (became thicker) with increasing gum concentration; nevertheless all flow behavior indexes were <1, indicating shear thinning. At xanthan and guar gum levels of 1.0% overall yields of post agitation batter adhesion increased 37% and 16% from the control, respectively (Hsia and others 1992).

Similar results to the previous were recently reported by Altunakar and others (2006) who evaluated the effect of hydrocolloids and starches for chicken nugget batter formulations,
including four starches (oxidized amylomaize, corn, pregelatinized tapioca, and waxy maize starch) and five gums (guar, gum Arabic, xanthan, HPMC and MC). All gum types provided higher consistencies than starch. Guar gum, xanthan, HPMC, and pregelatinized tapioca starch were all significant in aiding pickup, with pregelatinized tapioca starch producing the highest pick-up. HPMC and xanthan were found to contribute to a softer texture; other gums were not significantly different from the control in texture.

The effects of CMC on batter were further studied by Xue and Ngadi (2006). CMC was added to 0.5, 1.0, or 1.5% (w/w db) to batters in combination with flours (rice, corn, and wheat). The addition of CMC significantly increased the gelatinization temperature. Gelatinization temperature showed a direct relationship with increasing gum concentration; which was attributed to a stable starch-CMC interaction (Rojas and others. 1999). Because CMC has a strong affinity for water, products containing CMC showed improved stability during shipping and storage freeze/thaw cycles. CMC was found to exhibit more significant impacts when combined with rice and/or corn batter than with wheat batters. CMC may display a weakened effect when paired with wheat flour due to water-binding competition between gluten and CMC (Xue and Ngadi 2006).

Fiszman and others (2005) attributed the positive influence of CMC concentrations on adhesion to increased viscosity; the same correlation was not observed with HPMC. HPMC did not produce a significant difference in batter pick-up using the same concentration as CMC (1.0%). They concluded that HPMC and CMC were incompatible in batter applications with a high total percent usage. The hydrocolloids provided a tight encapsulation that could only release air and moisture when a build-up was produced. Mukprasirt and others (2001) found that MC displayed good substrate binding but inadequate freezing characteristics. Fiszman and
others (2005) utilized the thermogelling property of MC to eliminate the par-fry step prior to freezing. The batter was set using boiling water, and then cooked with convection oven (Fiszman and others 2005).

The use of hydrocolloid C-Trim, rich in oat β-glucan from oat bran, was studied by Lee and Inglett (2007) to replace wheat flour at 2 and 4% (w/w db) basis. Batters containing C-trim allowed for a significant increase in water holding capacity and thus batter viscosity. The high C-Trim concentration formulation resulted in a softer texture due to the large percentage of β-gluten.

Gluten

Gluten is a distinctly unique protein and extensively utilized in the baking industry to provide functionality and texture to a product. Gluten is the reason why for many centuries wheat has been the base ingredient in baking. This unique protein provides strong visco-elastic characteristics that aid in trapping moisture and air, and grant a chewy cohesive texture (Day and others 2005). Commercial vital wheat gluten is primarily composed of protein, starch, lipids, and fiber (Day and others 2005). These components interact to produce the desirable defining characteristics of gluten. The lipid content in gluten is very low; however these lipids form linkages with protein upon washing (Day and others 2005). These lipoprotein interactions create desirable visco-elastic properties. Even though gluten contains approximately 75% protein and is insoluble in water. Gluten assists in water binding. In contrast to vital gluten, de-vital gluten lacks the cohesiveness of vital gluten. Therefore in applications where elasticity is undesirable but water-binding is essential, de-vital wheat gluten is preferred. Enzyme-solubilized gluten is another gluten derivative that may improve loaf volume and provide foam stability and emulsion formation, however often produces off-flavors. In extruded meals or cereals, gluten increases
texture, crispiness, and rolling action during the process. The high glutamic acid in gluten is responsible for vital functional characteristics of hydrophilic-hydrophobic emulsification, hydrophilic water retention, and overall solubility (Day and others 2005). In batter formulations, gluten characteristics act very similarly; gluten aids in water-retention, adhesion, crisping and the trapping of air formed by leavening (Breuil 2001; Salvador and others 2005). Gluten, due to high protein content, increases browning levels within a product, thus the amount utilized is very critical. Salvador and others (2005) showed that the addition of vital wheat gluten at 7.5% of total batter weight (w/w db) significantly increased batter pick-up, red color (a*) formation after first heat impact, and apparent viscosity.

Dextrin

Dextrin is one type of starch derivatives and can be obtained from various sources. Dextrin is manufactured by a dry reaction under low pH and high temperature conditions. Dextrin can provide adhesion, clarity, binding and crispiness. Salvador and others (2005) showed that the highest crispiness value of coated squid rings was obtained from the batter containing dextrin. The use of dextrin prolonged the crispness of batter-fried squid rings after frying (Baixauli and others 2003).

Leavening

Leavening agents commonly utilized in the food industry include sodium bicarbonate (NaHCO₃), sodium acid pyrophosphate (Na₂H₂P₂O₇) and sodium aluminum phosphate (NaAl₃H₁₄(PO₄)₈•4H₂O). These agents provide fast acting air (volume) within a product when in contact with water, and can be utilized as a cheap alternative to yeast. Salvador and others (2002) found that the batter formulation containing 3.1% leavening (w/w db) produced a softer
bite when compared to the control with no leavening. Formulations without leavening required a significantly greater force to break coating, thus resulting in a harder texture. On the other hand batter formulas with high amounts of leavening impart a spongy texture. This sponginess could be a result of increased breading oil absorption into the air-void volume during frying.

Surfactants

Surfactants are molecules that enable hydrophobic/hydrophilic interaction in order to lower the surface tension of a liquid or between liquids. Lowering surface tension provides a larger distribution of liquid over a surface and thus a substance spreading. Surfactants are not traditionally used in batter formulations or chicken nuggets but may provide some valuable coating characteristics. Maskat and Kerr (2004) studied the addition of surfactants (polyethylene sorbitan mono-oleate) to batter formulations in attempt to improve adhesion to poultry substrates. It was hypothesized that the decrease of surface tension, a defining characteristic of surfactants, would aid in the flow and coverage of fluid substances. The reduction in surface tension would decrease the substrate-coating interaction angle, thus improving adhesion. However, results showed that as surfactant concentration increased both the surface tension and the adhesion decreased significantly, which was contradicted to the proposed theory (Maskat and Kerr 2004). They identified that the lack of adhesion was due to the increased amount of absorbed frying oil, and concluded that batter viscosity was a better indication of adhesion.

Salt

Salt (NaCl) has three functions within dough and bakery products. It provides flavor, inhibits yeast and mold formation, and strengthens the dough matrix. Salt can be added to dough at 2% and will counteract sticky or soft dough (Baking 1988). Volumes of the pre-baked dough
also showed larger increases with a 1% addition of salt; gas retention was higher than with salt-free dough. It was also stated that with that addition of salt, the amount of available water for other components decreases, thus causing a tougher dough (Baking 1988). Salt may impact the batter properties by influencing starch gelatinization process (Salvador and others 1982). All formulas containing salt at concentrations 2.5% (w/w db) or less, regardless of other ingredients, had a significantly higher gelatinization temperature than those batters without salt (Salvador and others 2003). Higher concentrations were not evaluated due to consumer palatability. The addition of salt can also drastically transform batter rheological properties (Salvador and others 2003). Batters containing salt appeared to be less elastic; however salt contributed statistically insignificant effects on the final product texture. Salvador and others (2002) evaluated the effect of salt (5.5%) in a wheat and corn flour batter on final fried characteristics. In comparison with other batters, the one containing salt had a significantly lower apparent viscosity, which was considered to be desirable for ease in substrate application.

Enzyme Modification of Starch

Different enzymes will act on the latter starch structures in vastly different ways. Enzymes such as amyloglucosidase, aka glucoamylase, can be utilized to break down both the amylose and amylopectin structures (Bazin et al., 2004). This enzyme in particular will completely hydrolyze the starch granule into glucose. However, when partially hydrolyzed the starch will exhibit a porous-like structure (Bazin et al., 2004). Glucoamylase reacts under specific pH and temperature conditions to first break the carbon α-1,4 linkages as it proceeds inward towards the center of the starch. When approaching a 1-6 carbon linkages the enzyme will slow the rate of hydrolysis but will cleave this bond as well. Once it reaches the starch granule center, the enzyme will proceed outward on either another tangent or the same pathway.
it produced previously (Bazin et al., 2004). Depending on the starch source type however, dictates the mode of entry and exit of the enzyme action. US Patent 20040067560A1 outlines the means for a hydrophobic starch modification for the primary use of fluid absorption and delayed release of encased fluid (Bazin et al., 2004). After the desired hydrolysis of amyloglucosidase occurs, the starch structure is quite open. Due to this reaction occurring below gelatinization temperature and within a lower pH solution, the starch surface is changed into a hydrophobic state. Once the starch dries, the granules can then be introduced to a liquid molecule of lipophilic or other hydrophobic substance. The granule, at this state readily adheres, or in this case absorbs these substances.

Sensory Evaluation

Sensory evaluation is the primary means of evaluating coated products, and the important sensorial attributes include adhesion, texture of coating, texture of substrate, oiliness, and moisture. Most coating application studies use shear force to evaluate cooked coating texture. In a study by Antonova and others (2003), trained panelists were asked to bite through a breaded nugget and then rate the level of crispiness based on a 9-point hedonic scale. Moisture, fat content, and texture of the nuggets were also measured, and ultrasonic nondestructive technique was used to assess the texture/crispiness. Transmitters were placed on either side of the sample, and sound waves passed from one transmitter to another. As moisture increased with holding time, the velocity of sound waves decreased. Positive correlation was observed between the ultrasonic readings and the panelist results. They concluded that ultrasonic nondestructive technology could be a predictor of crispiness.

In a study by Salvador and others (2002), coating (made of salt, corn flour and leavening) was evaluated for ingredient functionality on fried texture. The study carefully removed from
the substrate and cut into 20×10×2 mm pieces. Three coating strips were taken from each sample for analysis. A cylinder plunger attached to a TA-XT2 texture analyzer moved at a speed of 1 mm/sec towards the platform containing the coating piece. The platform was flat with a 5-mm diameter opening where plunger would penetrate through the sample. Maximum force and slope were determined by sensor on the texture analyzer, and sample profiles were averaged by a data analysis program. The resulting crispy product detailed a multiple crack, or peak profile but its maximum force was less than other samples. Salvador detailed that leavening had an effect on crisp texture while the other ingredients did not.
Hypothesis and Justifications

Previous works have shown the impacts of different starches and starch derivatives on fried chicken nuggets. It was hypothesized that starch derivative is critical to the textural attributes of bake-only nuggets. This study attempted to create a bake-only nugget that has similar textural characteristics as a fried chicken nugget through integrating starch derivatives. This research systematically investigated the influence of starch source and modification on the properties of batter and subsequently baked nuggets. Also efforts were undertaken to deliver the fatty mouth-feel with reduced amounts of fat while still maintaining a free-flowing machine able coating mixtures. With the increasing level of obesity amongst our nation and especially our children, we need to find better ways to produce the products they love without the large amount of oil. It was proposed that the defining characteristics of fried chicken nuggets could be implemented into bake-only nuggets.

Objectives

There were two main objectives in this study, and both objectives studied the effect of starch derivatives on the textural attributes of bake-only nuggets in comparison with the traditional fried version. The first objective was to compare the oxidized starch from different starch sources, including corn, wheat, rice, tapioca, and potato. The second objective was to compare enzyme-modified starch from different sources, including corn, wheat, rice, and tapioca, on their effectiveness of carrying liquid oil into a bake-only coating system. Enzyme modified starch has yet to be utilized for such an application. This application will aid in the delivery of desired mouth-feel characteristics that have yet to be delivered in bake-only food products.
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CHAPTER 3

PUBLICATION 1

Enzyme-Modified Starch as an Oil Delivery System for Bake-Only Chicken Nuggets

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Short version of title: Bake-only chicken nuggets…

Choice of section: Food Chemistry

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Abstract

This study investigated the effects of enzyme modification on starch as an effective oil delivery system for bake-only chicken nuggets. Various native starches were hydrolyzed by amylglucosidase to a hydrolysis degree of 20-25% and plated with 50% (w/w, starch dry basis) with canola oil to create a starch-oil matrix. This matrix was then blended into a dry ingredient blend for batter and breader components. Nuggets were prepared by coated with predust, hydrated batter and breader, and the coated nuggets were steam-baked until fully cooked and then frozen until texture and sensory analyses. The enzyme-treated starches showed a decrease in gelatinization range and pasting viscosities for all starch types. For textural properties of nuggets, no clear relationship was found between peak force and starch source or amylose content. Sensory attributes related to fried foods (e.g., crispness and mouth-coating) did not significantly differ between bake-only nuggets formulated using the enzyme-modified starches and the partially fried and baked ones. The present findings suggest that enzyme-treated starches can deliver sufficient quantity of oil to create sensory attributes similar to those of partially fried chicken nuggets. Further study is needed to optimize the coating formulation of bake-only chicken nugget to become close to the fried one in sensory aspects.

Keywords: enzyme modification, amylglucosidase, starch, bake-only chicken nuggets, oil delivery

The authors have declared that no conflict of interest exists.
Practical Application: The food industry has become increasingly focused on healthier items. Frying imparts several critical and desirable product functionalities, such as developing texture and color, and providing mouth-feel and flavor. The food industry has yet to duplicate all of the unique characteristics of fried chicken nuggets with a baking process. This study investigated the application of enzyme-modified starch as an oil delivery system in bake-only chicken nugget formulation in attempts to provide characteristics of fried items. This information is useful to improve the nutritional value of fried food by eliminating the frying process while preserving the desired characteristics of fried products.
Introduction

Frying contributes many desirable sensory attributes to foods, but at the same time also significantly increases the oil content in the finished products. Due to the increasing consumer awareness of food labels and nutritional requirements, the food industry is trying to reduce the oil content in fried or partially fried food products while still maintaining their desirable sensorial characteristics. Studies have been conducted to reduce the percentage of oil absorbed in deep-fried food, which mostly focused on elimination of the pre-frying step or ingredient substitution to limit total oil content.

Fiszman and others (2005) reviewed a developed a patented process by eliminating the pre-frying step in deep fried food, which contributes the majority of oil absorbed in fried food. They incorporated methylcellulose in the batter formulation and coagulated the batter layer in a hot water bath (~ 70-80°C) for 30 sec before placing into a microwave, conventional or Infrared oven prior to freezing and final frying. Salvador and others (2008) reported 4-15% reduction of oil absorbed by using this patented method in 4 food matrices (minnow, pork patty, cheese, and squids) while still maintaining good sensory acceptability. Jackson and others (2006) compared baking verses frying of chicken nuggets and found that baking reduced fat calories by at least 67% compared with frying without affecting consumer acceptability in dry batter applications. Salvador and others (2005) evaluated the addition of different ingredients (wheat starch, modified corn starch, dextrin, dried egg, and gluten) to the batter mixture containing methylcellulose without the use of a pre-frying step. The additions of gluten to the batter resulted in the highest pick-up and significantly lower oil absorption than the control without the additional ingredient (Salvador and others 2005). Jackson and others (2006) compared rice flour and wheat flour in a dry coating treatment of baked and fried chicken nuggets and found rice
flour absorbed less oil than wheat flour. Lee and Inglett (2007) showed that the incorporation of β-glucan-rich hydrocolloid, C-Trim 30, increased batter pick-up and reduced oil content in fried carrot. Altunakar and others (2004) studied the effects of batter containing different starch types (common corn, amylomaize, waxy maize, and pregelatinized tapioca) on batter-fried chicken nuggets. The addition of pregelatinized tapioca starch resulted in the highest batter pick-up and the lowest oil content.

Amylolytic enzymes such as α-amylase and amylogucosidase are capable of breaking down starch molecules, both amylose and amylopectin, by hydrolyzing α-1→4 glucosidic linkages. When starch is partially hydrolyzed by amylolytic enzymes at the native, granular state, a porous structure can be observed in most starches. The starch source type, however, dictates the mode of entry and exit of the enzyme action. The unique porous structure of enzyme-hydrolyzed starch finds applications such as fluid absorption and delayed release of encased fluid while maintaining its powder form for ease of processing (Bazin and others 2004). In traditional style batters, the amount of oil loading is very low. However, the addition of oil often results in clumps or a dough-like structure. This is therefore not suitable for long term storage, and traditionally batter manufacturers limit the amount of any liquid added to a dry blend. This work intended to use hydrolyzed starch as a vehicle to deliver a small amount of oil to the bake-only chicken nuggets, which was believed to improve the sensorial attributes of baked-only products. The formulation and process were studied to incorporate the oil-plated hydrolyzed starch in the coating system, and the sensory evaluation of the finished baked-only chicken nuggets was conducted using a trained panel.

Materials and Methods
Materials

Corn starches (waxy, common, and Hylon V) were provided by National Starch (Bridgewater, NJ, USA). Rice starch was extracted from waxy, long-grain, and medium-grain rice following the alkaline steeping method of Yang and others (1984). The waxy rice was purchased from a local oriental store, and the long-grain (Wells) and the medium-grain (Bengal) rice samples were obtained from the 2007 crop and provided by the University of Arkansas Rice Processing Program.

Amyloglucosidase was purchased from Sigma-Aldrich (St. Louis, MO) and used as received without further treatment. One unit of amyloglucosidase (A-3042; Aspergillus niger, 11,500 units/mL) will produce 1.0 mg of glucose from starch at pH 4.5 and 55°C in 3 min. Commercial grade wheat flour and orange cracker meal were provided by Newlyweds Foods Inc. (Springdale, AR). Salt, sodium bicarbonate, and sodium acid pyrophosphate were products of Morton Salt (Chicago, IL), Church & Dwight (Princeton, NJ), and Innophos, Inc. (Cranbury, NJ), respectively. Gluten was obtained from MGP Ingredients, Inc. (Atchison, KS).

Enzymatic Hydrolysis of Starch

Starch was combined with 20 mM acetate buffer at pH 4.5 to prepare 25% (w/w) slurry. The slurry was maintained at 55°C with constant stirring for 30 min prior to the addition of amyloglucosidase. Depending on starch type, the enzyme concentration (1-2 units per mg starch) or hydrolysis duration (2-24 hr) was altered to obtain a 20-25% hydrolysis degree (Bazin and others 2004), which was determined by the ratio of the amount of glucose release to the starch dry weight. The hydrolyzed glucose was determined by the phenol-sulfuric acid method (Dubois and others 1956). Upon the completion of hydrolysis, the reaction was terminated by a reduction
of pH to 3.0 with 2 M H₂SO₄ for 3 min, and then the pH was adjusted to 5.5 with 1 M NaOH (Bazin et al., 2004). The slurry was washed 1× volume of distilled water, vacuum filtered with Whatman #4 filter paper, and dried at 40°C until a moisture content of 10-12%. The rice starch slurry was centrifuged at 9,800 ×g for 15 min due to difficulty in filtrating (Kuakpetoon and Wang 2001).

Morphology and Physicochemical Properties of Starch

The morphology of enzyme-treated native and annealed starches was taken with a Philips XL-30 scanning electron microscope (SEM, Philips Electron Optics, Eindhoven, Netherlands) at an accelerating voltage of 6.0 kV. Starch granules were sprinkled onto double-backed cellophane tape attached to a stub before coating with gold-palladium.

Thermal properties of native and modified starches were analyzed by a Perkin-Elmer Pyris-1 differential scanning calorimeter (DSC, Perkin-Elmer Co., Norwalk, CT). The DSC was calibrated with indium prior to analysis; an empty sample pan was used as reference. Starch was added to DSC aluminum pans (~4 mg, db) and hydrated with 8 µL deionized water via a microsyringe. Pans were hermetically sealed and allowed to equilibrate for at least one hour prior to scanning. Starch samples were scanned from 25°C to 120°C at 10°C/min, and onset (To) and peak (Tp) temperatures and enthalpy (∆H) were computed with Pyris data analysis program.

The pasting properties of native and modified starch samples were determined at 10% solid (dry basis) using a Micro Visco-Amylo-Graph (MVAG-VE, C.W. Brabender Instruments, Inc., New Jersey, USA). The slurry was heated from 50°C to 95°C at 3°C/min, held at 95°C for 5 min, and then cooled to 50°C at 3°C/min.
Oil Plating Protocol

Enzyme modified starch was plated with 50% (w/w, dry starch basis) canola oil. Starch of 100 g (db) was weighted into a dry mortar vessel, and then 50 g canola oil was added slowly as pestle distributed oil into modified starch until starch became dry and powder-like. A metal spatula was used in aiding in scraping sides for uniform distribution. Plated samples were prepared prior to batter formulation and addition.

Batter and Breader Preparation Protocol

Batter and breader formulas were prepared with the plated enzyme modified starch (Table 1). For each test formula, the plated starch replaced the main ingredient within both batter and breader formulation; the plated starch replaced the wheat flour within the batter and the crackermeal within the breading. All ingredients were separately weighted and blended together in a bench-top Kitchen Aid mixer for 5 min. Blended formulas were stored in zip-lock bags prior to application. All dry batter mixtures were hydrated at 2:1 (wet: dry) ratio with 4°C tap water and mixed with a wire whisk for 2 min prior to measurement. The batter rheological properties were measured with a Haake VT 550 Viscometer (Thermo Scientific, Newington, NH) using MV-DIN sensor. Shear stress and viscosity were measured using a controlled shear rate increased from 0.10 to 100 s⁻¹ within 200 sec with a stress to rate time curve duration at 10 sec.

Nugget Preparation

Pre-formed chicken nuggets were obtained from Tyson Foods, Inc. (Springdale, AR), thawed and ice crystals removed prior to coating. Nuggets were dusted with flour, battered, breaded and fully cooked via open steam (87°C for 3.5 min) and convection baking (204°C for 6
Nuggets were immediately individually quick frozen (IQF) for 20-30 min post thermal processing and stored at -20°C until further analysis. The lipid content in the coating of nuggets from those prepared with no starch (Control) and with plated enzyme-treated starches as well as from a commercial partially fried sample (Chicken Nuggets, Tyson Foods, Inc., Springdale, AR) was determined by using Soxhlet extraction with petroleum ether overnight.

Breading Pick-Up

Coating pick-up measurements were obtained at intervals during the nugget preparation. Blank nuggets were weighed and then weighed again after predust and finally after breading. Five nuggets were used to perform a representative sample for each pick-up measurement. These nuggets were sampled from each of two produced nugget batches within a test formulation; this totals ten nuggets sampled for pick-up per test. Each test totaled eight nuggets; forty nuggets were produced in each batch to ensure uniformity of breading material. Pick-up percentages were calculated with the following formula.

\[
\text{Pick-up} = \left[ \frac{B}{B+S} \right] \times 100
\]

Where B = weight of the coating and S = weight of the substrate

Nugget Texture Analysis

Nuggets were reconstituted by baking frozen nuggets in a convection oven at 204°C for 10 min and analyzed with an acoustic envelope detector (A/AED) for TA.XT plus Texture Analyzer. Five nuggets per treatment were sliced three times per nugget with a 5-mm diameter blade. The blade cut nuggets 12 mm deep at 1.0 mm/s speed with 2.0 g trigger force. This protocol was developed from preliminary testing. Texture was analyzed based on the correlation
between force (N) and acoustic measurements (Root Mean Squared (RMS) in decibels, db). All treatments were measured with five replications and bisected in triplicate per nugget.

Descriptive Sensory Analysis

Sensory analysis was conducted by 8 panelists trained according to the Spectrum® method (Sensory Spectrum Inc., Chatham, NJ) at the University of Arkansas Sensory Service Center (Fayetteville, AR). As summarized in Table 2, 5 sensory attributes related to the texture properties of chicken nugget were developed at 4 stages: before first bite, at first bite/chew, chewdown, and residual characteristics. A commercial chicken nugget sample (Tyson Foods, Inc., Springdale, AR) was used, as a product-specific reference, for panelists to consider their experience within the chicken nugget category in assessing their perceived intensity (Meilgaard and others 2007). The reference intensity for each attribute was determined on a 15-point numerical scale through panel discussion (we used a 9 point scale).

At ten minutes after baking, a total of 7 chicken nugget samples (i.e., 1 control nugget and 6 treatment nuggets formulated by enzyme-modified starches) were presented one after another to panelists. Each sample (3 cm × 5 cm × 1 cm) (these dimensions are wrong placed in a soufflé cup with a three-digit code was randomly presented in replicate. For each sample, 5 sensory attributes were evaluated on 15-point (9-pts) numerical scales with references. Panelists were presented with spring water and unsalted crackers between the sample presentations for cleansing their palates.

Statistical Analysis
Data analysis was conducted using JMP software (Version 10.0, SAS Institute, Cary, NC). To determine the effects of added starches on texture attributes in the bake-only chicken nuggets, one-way analysis of variance (ANOVA) was used, followed by mean separation using Tukeys HSD at $\alpha = 0.05$ when there was a statistical significance. Descriptive sensory data were analyzed using a generalized linear model (GLM) with starch type as a fixed effect. The $\alpha$-level was 0.05.

Results and Discussion

Starch Morphology

The representative SEM micrographs of hydrolyzed starches by amyloglucosidase are presented in Figure 1. Regardless of starch type in this study, amyloglucosidase hydrolyzed starch granules via multiple attacks of localized digging, resulting in pits into the granules. Hylon V exhibits fewer but larger pits among all starches, whereas waxy rice starch seems to experience minimal hydrolysis. Because all starches were hydrolyzed to a targeted hydrolysis level of 20-25%, the differences in morphology could be attributed to their differences in chemical structure and granular organization. Similar observations were previously reported by O’Brien and Wang (2008).

Thermal properties

The gelatinization properties of native and enzyme-treated starches as measured by DSC are presented in Table 3. The extent of hydrolysis had more significant impacts on the gelatinization temperatures of rice starches than on those of corn starches. All three rice starches exhibited significantly higher onset ($T_o$) and peak ($T_p$) gelatinization temperatures of 3.4-4.8°C
and 1.6-3.3°C, respectively, after the targeted hydrolysis of 20-25%; however, only common corn starch showed an increase in peak gelatinization temperature. Hylon V and waxy rice starch exhibited a significant decrease in gelatinization range after the hydrolysis. The gelatinization enthalpy (ΔH) was not changed by the hydrolysis for all starches. The increase in gelatinization temperature indicates hydrolysis of the amorphous lamellae by amyloglucosidase because the amorphous lamellae facilitate the destabilization and then melting of the crystalline structures (Donovan 1979). The unchanged ΔH implies that the crystalline structures were not destroyed or altered by amyloglucosidase for all starches. The present results suggest that the melting of the crystalline structures in rice starches was greatly assisted by the amorphous lamellae, which was not observed for corn starches. It is possible that the steeping in the commercial wet milling process of isolating corn starch is similar to annealing and thus results in improved crystalline structures that are not as easily affected by the amorphous lamellae.

Pasting properties

The pasting profiles of enzyme modified starch (Figure 2) showed a decrease in pasting viscosities for all source types when compared with their respective unmodified counterparts. The most significant difference in overall profile was noted for both waxy starches, which was due to the degradation of amylopectin, thus resulting in a significant decrease in viscosity (Donovan 1979). Because amylose is mainly present in the amorphous lamellae, amyloglucosidase would act more on amylose than on amylopectin, which would not greatly reduce viscosity. More changes were observed in amylose-containing rice starches than amylose-containing corn starches, which were attributed to the improved crystalline structure as stated
previously from the wet milling steeping process so the enzymatic hydrolysis had less impact on the pasting viscosities of amylose-containing corn starches.

Batter Viscosity

Figure 3 shows the differences in batter viscosity between the control formulation of wheat flour and the test formulations, in which wheat flour was replaced by enzyme-modified starch, when hydrated with 4°C water. Enzyme-modified starch produced minimum cold viscosity, whereas wheat flour developed a higher cold viscosity due to the gluten protein (Day and others 2006). Slight differences were noted among modified starches, but in general all test batters displayed shear thinning. Enzyme-modified high amylose corn starch showed a minimal ability for water absorption at a cold state and developed viscosity over time as other starches.

Coating Pick-up

Coating pick-up was calculated at each step to identify the step that contributed to the most pick-up, and the results are presented in Table 4. The predust consisted of wheat flour only, thus the predust results indicate some inconsistency in manual coating. There were differences in pick-up of batter and breading between the control and some test formulations with the control formulation showing the most difference from Hylon V and long-grain and waxy rice starches at the batter and breading stage. It was expected to exhibit more pick-up compared to the control; however, no differences among sources or amylose level were identified. Altunakar and others (2004) experienced decreased breading pick-up with amylomaize starch, which however was not observed in this study. The lipid content (as is) in the coating of the control and the commercial sample was 4.8% and 17.1%, respectively. All test samples had a similar lipid content of 6.9%,
which supports previous results that no difference was found between the control and the test formulations in coating pick-up. The results show that plated starch delivered around 2% lipid into the coating system.

Texture and Acoustic Evaluation

The results of peak force and acoustic data are presented in Table 5. There was no clear relationship between peak force and starch source or amylose content. Nuggets prepared with waxy corn starch required the least force to penetrate the sample, while those with waxy rice starch required the most force. However, the acoustic root mean squared (RMS, decibels (db)) results were positively correlated with amylose content. The more audible treatments contained starches with more than 20% amylose content (Hylon V, common corn, and long-grain rice). The differences among treatments by comparing treatment means (Table 6) were also determined to understand the difference within the treatment as well as the effect of sequence in analysis. Treatment repetition five was more audible and required more force to cut the coating, which indicates that the delay in measurement contributed to harder texture. Post baking retrogradation of crust was proposed for the increase in cutting force over time. Antonova and others (2003) reported a positive relationship between peak force measured by an Instron Universal Testing machine using a Kramer shear-compression cell and sensory crispness by a trained panel, however it was as high correlation as ultrasonic velocity.

Sensory Evaluation

There was no significant difference among the bake-only chicken nuggets prepared with different enzyme-modified starches in all sensory attributes (Table 7): visual crust adhesion ($P = 0.25$), hardness ($P = 0.37$), crispness ($P = 0.32$), perception of moistness ($P = 0.14$), and mouth-
coating \( (P = 0.40) \). It is worth noting that the most distinctive sensory attributes of fried foods, i.e. “mouth-coating” and “crispness”, were not significantly different between the bake-only chicken nuggets formulated by enzyme-modified starches and the commercial partially fried and baked nugget. The “mouth-coating” attribute is regarded as one of representative sensory characteristics in fried foods (Leveaux and Resurreccion 1996; Mah and Brannan 2007). The “crispness” attribute is also one of the most distinctive texture attributes of fried chicken nugget (Antonova and others 2003). The lack of significant difference in the mouth-coating and crispiness attributes between the test and the commercial nugget samples was attributed to the combination of steaming and the addition of lipid-plated starch in the coating of the test samples. The present findings indicate that the enzyme-modified starches can provide sensory attributes of the bake-only nuggets with 6.9% lipid (theoretical?) content in the coating to be close to those of the partially fried and baked chicken nugget of 17.1% (theoretical?) lipid content in the coating.

Conclusion

Enzyme modification creates starches that are capable of delivering liquid oil into a dry system. The coating formulations containing oil-plated enzyme-modified starches improved the sensory attributes, such as crispness and mouth-coating, of bake-only chicken nuggets to be similar to a commercial partially fried and baked nugget sample.

Acknowledgments

The authors would like to thank Tonya Tokar for helping with sensory testing and Dr. Jean-Francois Meullenet for discussion of sensory results.
Author Contributions

Sarah Purcell conducted the research, collected the data, and drafted the manuscript. Ya-Jane Wang designed the study and interpreted the results. Han-Seok Seo analyzed and interpreted the sensory data.
REFERENCES


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Table 1-Batter and breader formulations for the control and the test samples.

<table>
<thead>
<tr>
<th>Ingredients (% as is)</th>
<th>Control</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Batter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat flour</td>
<td>92.5</td>
<td>48</td>
</tr>
<tr>
<td>Enzyme modified starch (plated)</td>
<td>0</td>
<td>44</td>
</tr>
<tr>
<td>Salt</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sodium acid pyrophosphate</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gluten</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Breader</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crackermeal</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>Enzyme modified starch (plated)</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 2-Lexicon for chicken nuggets.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Technique</th>
<th>Reference = Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before first bite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual crust adhesion</td>
<td>The degree that the crust/coating is separated from the meat block</td>
<td>Cut the sample one time and evaluate visual adhesion</td>
<td>Chicken nugget(^1) = 4.0</td>
</tr>
<tr>
<td>First bite/chew</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>The force required to compress the sample.</td>
<td>Compress or bite through sample one time with molars or incisors</td>
<td>Chicken nugget = 6.0</td>
</tr>
<tr>
<td>Crispness</td>
<td>The degree of sound and pitch heard when the sample is cracked, broken or</td>
<td>Compress sample with molars until sample breaks, crumbles or fractures</td>
<td>Chicken nugget = 3.0</td>
</tr>
<tr>
<td></td>
<td>compressed 1 time.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chewdown</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perception of moistness</td>
<td>The amount of wetness / oiliness felt on the surface of the chewed sample.</td>
<td>Chew sample three times</td>
<td>Chicken nugget = 3.0</td>
</tr>
<tr>
<td>Residual characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mouth-coating</td>
<td>The amount and degree of residue felt by the tongue when moved over the</td>
<td>Expectorate the sample and feel the surface of the mouth with the tongue</td>
<td>Chicken nugget = 3.0</td>
</tr>
<tr>
<td></td>
<td>surface of the mouth.</td>
<td>to evaluate.</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Commercial chicken nugget (Tyson Foods, Inc., Springdale, AR)
Table 3-Gelatinization properties of native and enzyme-modified starches.

<table>
<thead>
<tr>
<th>Starch</th>
<th>Modification</th>
<th>Gelatinization Temperature (°C)</th>
<th>Enthalpy (J/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Onset (Tc)</td>
<td>Peak (To)</td>
</tr>
<tr>
<td>Hylon V</td>
<td>No</td>
<td>71.0±1.1bc</td>
<td>76.0±0.8b</td>
</tr>
<tr>
<td></td>
<td>Enzyme</td>
<td>72.7±0.3b</td>
<td>76.9±0.2b</td>
</tr>
<tr>
<td>Common corn</td>
<td>No</td>
<td>68.5±0.5de</td>
<td>71.9±0.3d</td>
</tr>
<tr>
<td></td>
<td>Enzyme</td>
<td>70.1±0.3cd</td>
<td>74.1±0.2c</td>
</tr>
<tr>
<td>Waxy corn</td>
<td>No</td>
<td>69.7±0.5cd</td>
<td>73.8±0.6c</td>
</tr>
<tr>
<td></td>
<td>Enzyme</td>
<td>70.6±0.2cd</td>
<td>74.2±0.2c</td>
</tr>
<tr>
<td>Long-grain rice</td>
<td>No</td>
<td>72.5±0.1b</td>
<td>77.0±0.1b</td>
</tr>
<tr>
<td></td>
<td>Enzyme</td>
<td>76.3±0.9a</td>
<td>78.6±0.4a</td>
</tr>
<tr>
<td>Medium-grain rice</td>
<td>No</td>
<td>66.4±0.6e</td>
<td>71.5±0.3d</td>
</tr>
<tr>
<td></td>
<td>Enzyme</td>
<td>69.8±0.2cd</td>
<td>73.9±0.2c</td>
</tr>
<tr>
<td>Waxy rice</td>
<td>No</td>
<td>64.1±0.1f</td>
<td>69.2±0.2e</td>
</tr>
<tr>
<td></td>
<td>Enzyme</td>
<td>68.9±0.6bcd</td>
<td>72.5±0.6d</td>
</tr>
</tbody>
</table>

1Means ± standard deviations from 3 measurements within a column having the same letter(s) are not significantly different at 5% level based on Tukey’s HSD Test.
Table 4-Pick-up (%) for the control and enzyme-modified starch formulations\(^1\).

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Predust (%)</th>
<th>Batter/Breading (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control(^2)</td>
<td>3.8±0.5b</td>
<td>32.4±2.2a</td>
<td>36.2±2.1a</td>
</tr>
<tr>
<td>Hylon V</td>
<td>4.6±0.7ab</td>
<td>25.3±1.4b</td>
<td>30.0±2.0a</td>
</tr>
<tr>
<td>Common Corn</td>
<td>3.6±0.4ab</td>
<td>26.0±2.6ab</td>
<td>29.6±3.0a</td>
</tr>
<tr>
<td>Waxy Corn</td>
<td>5.8±0.6ab</td>
<td>27.4±0.7ab</td>
<td>33.1±1.3a</td>
</tr>
<tr>
<td>Long-grain Rice</td>
<td>8.6±3.1a</td>
<td>24.0±2.6b</td>
<td>32.6±0.5a</td>
</tr>
<tr>
<td>Medium-grain Rice</td>
<td>7.1±2.4ab</td>
<td>26.8±2.6ab</td>
<td>33.9±5.0a</td>
</tr>
<tr>
<td>Waxy Rice</td>
<td>4.4±1.3ab</td>
<td>25.2±1.8b</td>
<td>29.6±0.4a</td>
</tr>
</tbody>
</table>

\(^1\)Means ± standard deviations from 2 measurements within a column having the same letter(s) are not significantly different at 5% level based on Tukey’s HSD Test.

\(^2\)Control contains no starch.
Table 5-Mean texture and acoustic results of the coated nuggets prepared by the control and enzyme-modified starch formulations$^1$.

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Force (N)</th>
<th>Acoustic RMS (db)$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control$^1$</td>
<td>1.97ab</td>
<td>2.76a</td>
</tr>
<tr>
<td>Hylon V</td>
<td>2.06ab</td>
<td>2.71a</td>
</tr>
<tr>
<td>Common Corn</td>
<td>2.15ab</td>
<td>2.75a</td>
</tr>
<tr>
<td>Waxy Corn</td>
<td>1.51c</td>
<td>2.61b</td>
</tr>
<tr>
<td>Long-grain Rice</td>
<td>2.23a</td>
<td>2.79a</td>
</tr>
<tr>
<td>Medium-grain Rice</td>
<td>1.66bc</td>
<td>2.58b</td>
</tr>
<tr>
<td>Waxy Rice</td>
<td>2.35a</td>
<td>2.53b</td>
</tr>
</tbody>
</table>

$^1$Least square means from 5 replicates (3 slices per nugget) within a column having the same letter(s) are not significantly different at 5% level based on Tukey’s HSD Test.

$^2$Root means squared of raw acoustic data in decibels.

$^3$Control contains no starch.
Table 6—Differences between treatment sequence for texture and acoustic measurement

<table>
<thead>
<tr>
<th>Sequence Number</th>
<th>Force (N)</th>
<th>Acoustic RMS (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.60c</td>
<td>2.57b</td>
</tr>
<tr>
<td>2</td>
<td>2.0b</td>
<td>2.68a</td>
</tr>
<tr>
<td>3</td>
<td>2.0b</td>
<td>2.67a</td>
</tr>
<tr>
<td>4</td>
<td>1.92bc</td>
<td>2.73a</td>
</tr>
<tr>
<td>5</td>
<td>2.44a</td>
<td>2.72a</td>
</tr>
</tbody>
</table>

1Least square means within a column having the same letter(s) are not significantly different at 5% level based on Tukey’s HSD Test.

2Five nuggets per treatment were analyzed. Sequence number represents the order.

3Root means squared of raw acoustic data in decibels.
Table 7. Mean values (± standard deviation) of sensory attributes related to texture characteristics in the chicken nugget coated by no starch (control) and enzyme-modified starch formulations

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Visual crust adhesion</th>
<th>Hardness</th>
<th>Crispness</th>
<th>Perception of moistness</th>
<th>Mouth-coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial sample*</td>
<td>3.7 (±0.7)</td>
<td>6.1 (±0.5)</td>
<td>3.2 (±0.4)</td>
<td>2.8 (±0.3)</td>
<td>3.2 (±0.3)</td>
</tr>
<tr>
<td>Hylon V</td>
<td>4.1 (±0.6)</td>
<td>5.8 (±0.7)</td>
<td>2.6 (±1.2)</td>
<td>3.2 (±0.4)</td>
<td>3.3 (±0.3)</td>
</tr>
<tr>
<td>Common corn</td>
<td>4.4 (±1.0)</td>
<td>5.9 (±0.7)</td>
<td>3.2 (±0.8)</td>
<td>3.1 (±0.5)</td>
<td>3.1 (±0.2)</td>
</tr>
<tr>
<td>Waxy corn</td>
<td>4.1 (±0.8)</td>
<td>5.9 (±0.7)</td>
<td>3.1 (±0.4)</td>
<td>3.1 (±0.4)</td>
<td>3.2 (±0.3)</td>
</tr>
<tr>
<td>Long-grain rice</td>
<td>4.4 (±0.9)</td>
<td>5.6 (±0.6)</td>
<td>2.9 (±0.6)</td>
<td>3.2 (±0.3)</td>
<td>3.1 (±0.2)</td>
</tr>
<tr>
<td>Medium-grain rice</td>
<td>3.9 (±0.9)</td>
<td>5.7 (±0.4)</td>
<td>2.9 (±0.5)</td>
<td>2.9 (±0.3)</td>
<td>3.1 (±0.2)</td>
</tr>
<tr>
<td>Waxy rice</td>
<td>4.2 (±0.8)</td>
<td>5.7 (±0.8)</td>
<td>2.9 (±0.6)</td>
<td>3.1 (±0.4)</td>
<td>3.3 (±0.5)</td>
</tr>
</tbody>
</table>

There was no significant difference between nugget samples in all sensory attributes ($P > 0.05$).

*Commercial chicken nuggets from Tyson Foods, Inc. (Springdale, AR).
Figure 1 - Scanning electron micrographs of amylglucosidase-modified starches of A) Hylon V, B) common corn, C) waxy corn, D) long-grain rice, E) medium-grain rice, and F) waxy rice.
Figure 2-Pasting profiles of native and enzyme-modified starches by Micro ViscoAmyloGraph.
Figure 3-Cold batter viscosity of the control and enzyme modified starch formulations
APPENDIX

LETTER FROM ADVISOR

LETTER FROM PUBLICATION
Nov. 27, 2013

To Whom It May Concern:

This letter is to certify that Sarah Purcell had done at least 51% of the work for a submitted manuscript titled “Enzyme-modified starch as an oil delivery system for bake-only chicken nuggets”.

Sincerely yours,

Ya-Jane Wang, Ph.D.
Professor
Dec. 2, 2013

Dear Ms. Purcell,

We have received the following submissions to the *Journal of Food Science*: Food Chemistry section: JFDS-2013-1522 “Application of Oxidized Starches in Bake-Only Chicken Nuggets” and JFDS-2013-1481 “Enzyme-Modified Starch as an Oil Delivery System for Bake-Only Chicken Nuggets”, on which you are co-author and Prof. Ya-Jane Wang is corresponding author. Both papers are well into the review process, but we do not yet have enough completed reviews to send you a decision on either one. I thank you for your patience.

The *Journal of Food Science* (JFS) policy allows authors to re-use portions of their own JFS-published work without formal permission, and allows for research from an author’s dissertation or thesis to be published in the journal. We understand that you have included research from these studies in your thesis at the University of Arkansas. This does not present any conflict with publishing these papers in *JFS*, should they be accepted.

We hope you will continue to submit future work to IFT’s Scientific Journals.

Sincerely,

Amanda Ferguson
Associate Director, IFT Scientific Journals
Institute of Food Technologists
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CHAPTER 4

PUBLICATION 2

Application of Oxidized Starches in Bake-Only Chicken Nuggets

Sarah Purcell, Ya-Jane Wang*, Han-Seok Seo

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Short version of title: Bake-only chicken nuggets…

Choice of section: Food Chemistry
Abstract

There is a need to reduce the fat content in fried foods because of increasing health concerns from consumers. Oxidized starches have been utilized in many coating applications for their adhesion ability. However it is not known if they perform similarly in bake-only products. This study investigated the effects of oxidized modified starch for bake-only chicken nugget coating. Oxidized starches were prepared from seven starches and analyzed for gelatinization and pasting properties. Chicken nuggets were prepared using batter containing wheat flour, oxidized starch, salt and leavening agents prior to steaming, oven baking, freezing and final oven baking prior to sensory evaluation; the control nuggets contained no oxidized starch. All nuggets were analyzed for hardness by a textural analyzer, crispness by an acoustic sound, and sensory characteristics by a trained panel. The oxidation level used in the study did not alter the gelatinization temperature of all starches, but increased the pasting viscosity of corn, rice and wheat starches, and decreased that of tapioca and potato starches. There were differences in peak force and acoustic reading between treatments; however, the differences were not consistent with starch type or amylose content. The nuggets prepared by potato starch were perceived harder compared with those by waxy rice. Overall, the addition of oxidized starch did not provide improvement over the control containing no oxidized starch in all sensory attributes evaluated by the trained panel.

Keywords: oxidized starch, bake-only chicken nuggets, sensory attributes, texture
Practical Application: There is a need to reduce the fat content in fried food, such as chicken nuggets, because of increasing childhood obesity. Adhesion is one of the main characteristics that must be improved for the bake-only chicken nuggets, and oxidized starches are widely used in coating applications for their adhesion ability. This study investigated the use of different oxidized starches in steam-baked coated nuggets for their textural and sensorial properties. The findings from this research will provide an understanding of the contributions of starch derivatives to adhesion of bake-only nuggets, and future directions to perfect the batter formula for bake-only nuggets.
Introduction

Oxidized starches have been used in the food industry for their adhesion and coating properties. Oxidation is a type of conversion modification with hydroxyl groups on C2, C3, and C6 positions of starch anhydroglucose units to carbonyl and finally to carboxyl groups (Wurzburg 1986). Oxidation hydrolyses starch molecules, resulting in depolymerization, lower molecular size, and lower viscosities (Wang and Wang 2002). For batter applications, oxidized starches provide binding and stability without contributing a high viscosity (Kuakpetoon and Wang 2001). Kuakpetoon and Wang (2001) studied the starch origin (corn, rice and potato) and sodium hypochlorite levels (0, 0.8, and 2.0% w/w) on the structural changes and adhesion properties of oxidized starch. Adhesion was greatest in oxidized rice starch at 0.8% hypochlorite, whereas oxidized cornstarch had lower adhesion values for both oxidation levels. They concluded that the adhesion property of oxidized starch was mainly attributed to contact area and level of carboxyl groups. It was also noted that the contact area was impacted by size and shape of starch type.

Many studies have reported findings regarding coating formulation and its effect on the finished product texture and adhesion; however few studies have investigated the effect of starch in the formulation on coating properties. Altunakar and others (2003) studied the functionality of different starches (amylo maize, common corn, pregelatinized tapioca, and waxy maize) in the batters of deep-fried chicken nuggets in terms of texture, pick-up, moisture content, oil content, cooking yield, volume, and porosity. They reported that pregelatinized tapioca starch had the greatest contribution to pick-up, which was attributed to its high water-holding capacity as a result of pregelatinization. Starch addition to the formulations increased the crispness of fried nuggets, particularly after 12 min of frying. The nuggets containing amylo maize starch was
found to be the crispest because more amylose was released during the frying process, which
aided in forming a film to give a crispness and texture to the finished nuggets (Altunakar and
others 2003). Llorea and others (2006) studied the structure of starch in fried battered products
throughout the pre-frying, freezing and reconstitution frying of an industrial product. It was
found that oil penetrated into the starch granule at the pre-frying step, but the starch components
did not leach out of granules until the final frying step.

Most studies reported on the coating properties of regular fried battered food. Low-fat
coated products have not received much attention. Jackson and others (2006) investigated the
flour type (wheat vs. rice), batter type (wet vs. dry), and cooking method (baking vs. frying) in
the preparation of low-fat chicken nuggets. Baking produced nuggets with reduced fat calories
by at least 67% and a lighter color. All samples were found to be very tender, and there was no
difference between rice and wheat flour within the fried or baked category. All samples received
mean scores of “like slightly” for consumer acceptability, and all treatments were acceptable to
some segment of the population. However, no work has been reported on the use of steam
combination ovens for low-fat coated foods. This study aimed to investigate the use of different
sources of oxidized starches in steam-baked coated chicken nuggets for their textural and
sensorial properties.

Materials and Methods

Materials

Seven commercial native starches, including common corn (C*Gel 03420) and waxy
corn (C*Gel 04230) from Cargill (Hammond, IN), high amylose corn (Hylon V) and tapioca
from Ingredion (Bridgewater, NJ), potato (Pencook 10) from Penford (Centennial, CO), wheat
(Midsol 50) from MGP Ingredients, Inc. (Atchison, KS), and rice (Remy DR) and waxy rice (Remyline AX-DR) from Remy (Leuven, Belgium), were used in this study. Sodium hypochlorite (~5% active chlorine) was obtained from JT Baker. Commercial grade wheat flour and orange crackermeal were provided by Newlyweds Foods (Springdale, AR); salt, sodium bicarbonate, and sodium acid pyrophosphate were products of Morton Salt (Chicago, IL), Church & Dwight (Princeton, NJ), and Innophos, Inc. (Cranbury, NJ), respectively. The moisture content of each starch was determined using AACC Method 44-15A (AACC, 2000).

Oxidation of Starch

A starch slurry of 35% (dry basis) was prepared with distilled water by adding 500 g (dry basis) starch to a final weight of 1428 g in a 2-L reaction vessel. The vessel was stirred at 315 rpm in a 35°C water bath for 30 min to allow starch to hydrate (Wang and Wang 2003). The starch slurry was adjusted to pH 9.5 with 2 M NaOH prior to sodium hypochlorite addition. Sodium hypochlorite (10 g Cl/500g starch, 0.8% w/w db) was added slowly while maintaining at pH 9.5 with 2 M H₂SO₄ over a 30-min period. The slurry was maintained at pH 9.5 with 2 M NaOH for an additional 50 min to complete oxidation reaction. Afterward, the pH was adjusted to 7 with 2 M H₂SO₄, suction filtered (Whatman #4), and washed 1:1 (v/v) with distilled water prior to drying in a 40°C oven for 48 hr. Both oxidized rice starches were centrifuged (9,800 ×g for 15 min) instead of filtration due to difficulty of filtration, and the yellow top layer was discarded (Kuakpetoon and Wang 2001).

Physicochemical Properties of Starch
Thermal properties of native and modified starches were analyzed by a Perkin-Elmer Pyris-1 differential scanning calorimeter (DSC, Perkin-Elmer Co., Norwalk, CT). The DSC was calibrated with indium prior to analysis; an empty sample pan was used as reference. Starch was added to DSC aluminum pans (~4 mg, db) and hydrated with 8 µL deionized water via a microsyringe. Pans were hermetically sealed and allowed to equilibrate for at least one hour prior to scanning. Starch samples were scanned from 25°C to 120°C at 10°C/min, and onset (T_o) and peak (T_p) temperatures and enthalpy (H) were computed with Pyris data analysis program.

The pasting properties of native and modified starch samples were determined at 10% solid (dry basis) using a Micro Visco-Amylo-Graph (MVAG-VE, C.W. Brabender Instruments, Inc., NJ). The slurry was heated from 50°C to 95°C at 3°C/min, held at 95°C for 5 min, and then cooled to 50°C at 3°C/min.

Batter and Breader Preparation

Dry batter and breader formulas were prepared with the oxidized starch. For each test formula, 16% starch was added (taken from flour weight) to each batter and 12% (taken from crackermeal weight) for the breader (Table 1). All ingredients were separately weighted and blended together in a bench-top Kitchenaid mixer for 5 minutes. Blended formulas were stored in zip-lock bags prior to the coating process. All dry batter was hydrated at 2:1 (wet: dry, w/w) ratio with 4°C tap water and mixed until uniform with a wire whisk.
Batter Rheology

The rheological properties of all blended batters were evaluated. Batters were hydrated at 2:1 (wet:dry) with distilled water for 2 min prior to measurement. The batter rheological properties were measured with a Haake VT 550 Viscometer (Thermo Scientific, Newington, NH) using MV-DIN sensor. Shear stress and viscosity were measured using a controlled shear rate increased from 0.10 to 100s\(^{-1}\) for 200 sec with a stress to rate time curve duration at 10 sec.

Nugget Preparation

Pre-formed chicken nuggets were obtained from Tyson Foods, Inc. (Springdale, AR), thawed and ice crystals removed prior to coating application. Nuggets were dusted with flour, battered, breaded and fully cooked via open steam chamber (87°C for 3.5 min) and convection oven baking (204°C for 6 min). Nuggets were immediately individually quick frozen (IQF) for 20-30 min post thermal processing and stored at -20°C until further analysis.

Coating Pick-up

Coating pick-up measurements were obtained at intervals during the nugget preparation. Blank nuggets were weighed and then weighed again after predust and finally after breading. Five nuggets were used from each of two batches, forty nugget production runs to ensure similar pick-up. Pick-up percentages were calculated with the following formula.

\[
\text{Pick-up} = \left[ \frac{B}{(B+S)} \right] \times 100
\]

Where \( B = \text{coating} \) and \( S = \text{Substrate} \)
Texture Analysis

Nuggets were reconstituted by baking frozen nuggets in a convection oven at 204°C for 10 min and analyzed with an acoustic envelope detector (A/AED) for TA.XT plus Texture Analyzer. Five nuggets per treatment were sliced three times per nugget with a 5-mm diameter blade. The blade cut nuggets 12 mm deep at 1.0 mm/s speed with 2.0 g trigger force. This protocol was developed from preliminary tests. Texture was analyzed based on the correlation between force (N) and acoustic measurements (Root Means Squared, RMS) in decibels (db).

Descriptive Sensory Analysis

Descriptive sensory analysis for chicken nugget samples was conducted by 12 panelists trained according to the Spectrum® method (Sensory Spectrum Inc., Chatham, NJ) at the University of Arkansas Sensory Service Center (Fayetteville, AR). These panelists had extensive experience in evaluating sensory attributes of various food products including chicken nuggets. As summarized in Table 2, four sensory attributes (visual crust adhesion, hardness, crispness, and perception of moistness) related to the texture characteristics of chicken nugget were developed from our previous study (Purcell and others submitted). A commercial chicken nugget sample (Tyson Foods, Inc., Springdale, AR) was used as a product-specific reference, allowing panelists to consider their judgment within the category of chicken nugget (Meilgaard and others 2007). The reference intensity for each sensory attribute was determined on a continuous scale ranging from 0 to 15 (Meilgaard and others 2007).

At 10 min after baking in a conventional oven at 204°C, 8 chicken nugget samples (i.e., 1 control nuggets and 7 treatment nuggets containing oxidized starch were presented one after another to trained panelists. Each sample (3 cm × 5 cm × 1 cm) placed in a soufflé cup with a
three-digit code was randomly served in replicate. For each sample, four sensory attributes (Table 2) were evaluated on continuous scales ranging from 0 to 15 (Meilgaard and others 2007) at 3 distinctive stages: before first bite, at first bite/chew, and chewdown. Spring water (Clear Mountain Spring Water, Taylor Distributing, Heber Springs, AR) and unsalted crackers were served between the sample presentations for palate cleansing.

Statistical Analysis

Statistical analysis was conducted using JMP software (Version 10.0, SAS Institute, Cary, NC). To determine the effects of oxidized starches on texture characteristics in the bake-only chicken nuggets, one-way analysis of variance (ANOVA) was used, followed by mean separation using Tukey’s HSD at $\alpha = 0.05$. Descriptive sensory data were analyzed using a two-way ANOVA with treatment (i.e., starch type) as a fixed effect and panelist as a random effect, followed by mean separating using Tukey’s HSD at $\alpha = 0.05$ when there was a statistical significance.

Results and Discussion

Thermal Properties

The gelatinization temperatures and enthalpy of oxidized starch were not different from its native counterpart with the exception of tapioca starch where the peak gelatinization temperature was significantly higher in the oxidized starch (Table 3). Wang and Wang (2003) observed similar or increased gelatinization temperatures and unchanged enthalpy when common and waxy corn starch were oxidized by different levels of NaOCl (0.25-3% of active chlorine based on dry starch weight).
Pasting properties

All starches exhibited lower pasting temperatures after oxidation (Figure 1). The pasting viscosity profile for both types of corn and rice starches slightly increased, whereas that of wheat, tapioca and potato starches decreased after oxidation. Kuakpetoon and Wang (2001) reported that potato starch was more susceptible to oxidation compared with cereal starches, and the present results agree with their findings. Both the decrease in pasting temperature and the increase in peak viscosity were attributed to the formation of carboxyl group that allowed for more water penetration into the granules as result of weakened starch crystalline structure by its charged repulsion (Leach 1965). The most significant shift in pasting temperature was wheat starch. It is suspected that the high lipid content in wheat starch, which mostly exists as amyllose-lipid complex, might be destroyed during oxidation, thus decreasing pasting temperature without affecting the peak viscosity.

Batter Viscosity

Figure 2 shows the differences in batter viscosity between the control formulation of wheat flour and the test formulations in which wheat flour was partly replaced by oxidized starch when hydrated with 4°C water. The control showed the highest viscosity over time because of the gluten protein (Day et al 2006), followed by oxidized rice, oxidized waxy rice, and the others. The oxidized starches prepared in the present study had slightly higher viscosity than the enzyme modified starches prepared in a previous study (Purcell and others submitted), which was attributed to the presence of carboxyl groups from oxidation (Kuakpetoon and Wang 2001). Shear thinning was also displayed with the addition of oxidized starch, but was not as significant
as with enzyme modified starches. The higher viscosity values for rice starches was due to its small granule size, which was previously reported by Kuakpetoon and Wang (2001) when they compared native and oxidized rice, corn and potato starches.

Coating Pick-up

There was no statistical difference between the control and the test formulations in terms of percent pick-up of predust, batter/breading or total (data not shown), which can be explained by their similar batter viscosities (Figure 2). Slight differences in viscosities as mentioned previously, may not be significant enough to affect pick-up.

Texture and Acoustic Analysis

There were slight differences in peak force (N) between samples, however the differences were not consistent with starch type or amylose content (Table 4). Waxy corn starch treatment required the most force to cut the coating, while potato starch required the least. However, the opposite trend was noted for waxy corn and potato starch treatments in terms of their acoustic results. There was an impact of sample repetition on the peak force (Table 5). The nuggets analyzed first required the least force to break coating, but this trend was not exhibited for acoustic data with all samples being equally audible in all treatment repetitions.

Sensory Evaluation

Table 6 presents mean values of descriptive sensory attributes for each chicken nugget sample. There was a significant effect of treatment (i.e., starch type) on hardness in the chicken nugget samples \( (F = 3.21, \, P < 0.01) \). Post-hoc test indicated that panelists rated the chicken
nuggets containing oxidized potato starch significantly harder than the nuggets containing waxy rice starch ($P < 0.01$); however, these samples were not significantly different from the other samples including control, which contained only wheat flour without oxidized starch, for hardness ($P > 0.05$). There were no significant effects of starch type on other sensory attributes: visual crust adhesion ($P = 0.08$), crispness ($P = 0.08$), and perception of moistness ($P = 0.81$). These results demonstrated that overall, sensory attributes were not significantly different between the bake-only nuggets containing oxidized starches and the control without the addition of oxidized starch. Notably, for visual crust adhesion, the bake-only nuggets containing oxidized starches did not differ from the control nuggets, suggesting that oxidized starches did not improve the adhesion property of the control. Therefore, the preparation conditions and/or the formulation may need to be optimized in order to maximize the adhesion property by oxidized starch in the bake-only chicken nuggets.

Conclusion

Oxidized starches were prepared from various starches in batter and breading formulations to increase the adhesion and crispness of steam-baked chicken nuggets. Differences were noted in peak force measured by a texture analyzer, acoustic reading, and hardness by a trained panel. However, the oxidized starch prepared from various sources did not provide improved adhesion results over the control as evaluated by the descriptive sensory panel. A different oxidation level and/or more oxidized starch in the formulation may be needed to improve the products. Oxidized starches are often used in batter and coating to provide improved adhesion for fried items. However because of the necessary steam/oven process for bake-only
products, oxidized starches may need to be combined with other ingredient(s) to impart the
desirable textural and sensory attributes in bake-only products.

Acknowledgments
The authors would like to thank Tonya Tokar for helping with sensory testing and Dr. Jean-
Francois Meullenet for discussion of sensory results.

Author Contributions
Sarah Purcell conducted the research, collected the data, and drafted the manuscript. Ya-Jane
Wang designed the study and interpreted the results. Han-Seok Seo analyzed and interpreted the
sensory data.
REFERENCES


Xue J, Ngadi M. 2006. Effect of carboxymethylcellulose on thermal properties of batter systems formulated with different flour combinations. CSBE/SCGAB Annual Conference. Paper No. 06138S.
Table 1-Batter and breader formulations for the control and the test samples.

<table>
<thead>
<tr>
<th>Ingredients (%, as is)</th>
<th>Control</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat flour</td>
<td>94.5</td>
<td>78</td>
</tr>
<tr>
<td>Oxidized starch</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Salt</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sodium acid pyrophosphate</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Breader</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crackermeal</td>
<td>100</td>
<td>88</td>
</tr>
<tr>
<td>Oxidized starch</td>
<td>0</td>
<td>12</td>
</tr>
</tbody>
</table>
Table 2-Lexicon for chicken nuggets

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Technique</th>
<th>Reference = Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before first bite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual crust adhesion</td>
<td>The degree that the crust/coating is separated from the meat block</td>
<td>Cut the sample one time and evaluate visual adhesion</td>
<td>Chicken nugget$^1$ = 4.0</td>
</tr>
<tr>
<td>At first bite/chew</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>The force required to compress the sample.</td>
<td>Compress or bite through the sample one time with molars or incisors</td>
<td>Chicken nugget = 6.0</td>
</tr>
<tr>
<td>Crispness</td>
<td>The degree of sound and pitch heard when the sample is cracked, broken or</td>
<td>Compress sample with molars until the sample breaks, crumbles or fractures</td>
<td>Chicken nugget = 3.0</td>
</tr>
<tr>
<td>Perception of moistness</td>
<td>The amount of wetness / oiliness felt on the surface of the chewed sample.</td>
<td>Chew the sample three times</td>
<td>Chicken nugget = 3.0</td>
</tr>
</tbody>
</table>

$^1$Commercial chicken nugget from Tyson Foods Inc. (Springdale, AR)

This lexicon was developed from our previous study (Purcell and others, submitted).
Table 3-Gelatinization properties of native and oxidized starches\textsuperscript{1}.

<table>
<thead>
<tr>
<th>Starch</th>
<th>Modification</th>
<th>Gelatinization Temperature (°C)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Onset</td>
<td>Peak</td>
<td>Final</td>
<td>Enthalpy (J/g)</td>
</tr>
<tr>
<td>Common corn</td>
<td>No</td>
<td>69.2±0.1ab</td>
<td>72.7±0.2ab</td>
<td>77.2±0.6bc</td>
<td>11.8±0.2cd</td>
</tr>
<tr>
<td></td>
<td>Oxidation</td>
<td>68.5±0.5ab</td>
<td>71.9±0.3bc</td>
<td>76.5±0.3bc</td>
<td>11.6±0.3bc</td>
</tr>
<tr>
<td>Waxy corn</td>
<td>No</td>
<td>69.4±0.0a</td>
<td>73.5±0.1ab</td>
<td>78.7±0.2ab</td>
<td>14.3±0.3abc</td>
</tr>
<tr>
<td></td>
<td>Oxidation</td>
<td>70.0±0.1ab</td>
<td>73.8±0.2ab</td>
<td>78.7±0.1a</td>
<td>13.9±0.6abc</td>
</tr>
<tr>
<td>Rice</td>
<td>No</td>
<td>63.3±0.3ef</td>
<td>68.5±0.2de</td>
<td>76.1±0.6c</td>
<td>9.7±1.5de</td>
</tr>
<tr>
<td></td>
<td>Oxidation</td>
<td>64.0±0.0ef</td>
<td>69.5±0.2de</td>
<td>75.7±0.4bc</td>
<td>8.2±0.2e</td>
</tr>
<tr>
<td>Waxy rice</td>
<td>No</td>
<td>62.5±0.0ef</td>
<td>68.1±0.1def</td>
<td>77.0±0.9abc</td>
<td>12.8±0.0abc</td>
</tr>
<tr>
<td></td>
<td>Oxidation</td>
<td>63.5±0.2de</td>
<td>70.0±0.1cd</td>
<td>78.0±0.1abc</td>
<td>12.5±0.4abc</td>
</tr>
<tr>
<td>Wheat</td>
<td>No</td>
<td>62.0±0.2f</td>
<td>65.6±0.3g</td>
<td>69.8±0.4e</td>
<td>9.2±0.8e</td>
</tr>
<tr>
<td></td>
<td>Oxidation</td>
<td>62.7±0.9ef</td>
<td>66.0±0.6fg</td>
<td>69.9±0.4e</td>
<td>9.4±0.5de</td>
</tr>
<tr>
<td>Tapioca</td>
<td>No</td>
<td>65.4±0.1cd</td>
<td>70.3±0.3a</td>
<td>79.0±1.3abc</td>
<td>13.4±1.9bcd</td>
</tr>
<tr>
<td></td>
<td>Oxidation</td>
<td>67.5±0.5bc</td>
<td>72.2±0.7bc</td>
<td>79.6±1.5ab</td>
<td>13.4±0.2abc</td>
</tr>
<tr>
<td>Potato</td>
<td>No</td>
<td>63.1±1.1ef</td>
<td>67.3±0.6efg</td>
<td>73.1±0.6d</td>
<td>16.0±0.2ab</td>
</tr>
<tr>
<td></td>
<td>Oxidation</td>
<td>62.3±0.5f</td>
<td>66.1±0.5fg</td>
<td>72.7±0.4d</td>
<td>15.7±0.5a</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Means ± standard deviations from 3 measurements within a column having the same letter(s) are not significantly different at 5% level based on Tukey’s HSD Test.
Table 4-Mean texture and acoustic results of the coated nuggets prepared by the control and oxidized starch formulations.

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Force (N)</th>
<th>Acoustic RMS (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.96bcd</td>
<td>2.76a</td>
</tr>
<tr>
<td>Common Corn</td>
<td>2.0bcd</td>
<td>2.83a</td>
</tr>
<tr>
<td>Waxy Corn</td>
<td>2.76a</td>
<td>2.48b</td>
</tr>
<tr>
<td>Rice</td>
<td>2.41ab</td>
<td>2.58b</td>
</tr>
<tr>
<td>Waxy Rice</td>
<td>1.92cd</td>
<td>2.54b</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.33abc</td>
<td>2.79a</td>
</tr>
<tr>
<td>Tapioca</td>
<td>2.28abcd</td>
<td>2.88a</td>
</tr>
<tr>
<td>Potato</td>
<td>1.73d</td>
<td>2.83a</td>
</tr>
</tbody>
</table>

1Least square means from 5 replicates (3 measurements per nugget) within a column having the same letter(s) are not significantly different at 5% level based on Tukey’s HSD Test.

2Root Means Squared of raw acoustic data in decibels.

3Control contains no oxidized starch.
Table 5—Difference of texture and acoustic measurements within treatment sequence\(^1\).

<table>
<thead>
<tr>
<th>Sequence Number</th>
<th>Force (N)</th>
<th>Acoustic RMS (db)(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.85(b)</td>
<td>2.70(a)</td>
</tr>
<tr>
<td>2</td>
<td>2.25(a)</td>
<td>2.72(a)</td>
</tr>
<tr>
<td>3</td>
<td>2.11(ab)</td>
<td>2.74(a)</td>
</tr>
<tr>
<td>4</td>
<td>2.32(a)</td>
<td>2.69(a)</td>
</tr>
<tr>
<td>5</td>
<td>2.33(a)</td>
<td>2.69(a)</td>
</tr>
</tbody>
</table>

\(^1\)Least square means within a column having the same letter(s) are not significantly different at 5\% level based on Tukey’s HSD Test.

\(^2\)Root Mean Squared of Raw Acoustic data in decibels.
Table 6-Mean values of sensory attributes related to texture characteristics in the chicken nugget samples coated by oxidized starch formulations\(^1\).

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Visual crust adhesion</th>
<th>Hardness</th>
<th>Crispness</th>
<th>Perception of moistness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control(^2)</td>
<td>3.7±1.1a</td>
<td>5.5±0.9ab</td>
<td>2.9±0.7a</td>
<td>3.1±0.5a</td>
</tr>
<tr>
<td>Common corn</td>
<td>3.7±1.2a</td>
<td>5.5±0.6ab</td>
<td>2.9±1.0a</td>
<td>3.0±0.5a</td>
</tr>
<tr>
<td>Waxy corn</td>
<td>3.5±1.0a</td>
<td>5.3±0.7ab</td>
<td>2.2±1.2a</td>
<td>3.0±0.6a</td>
</tr>
<tr>
<td>Rice</td>
<td>3.5±1.1a</td>
<td>5.3±0.7ab</td>
<td>2.1±1.2a</td>
<td>3.1±0.4a</td>
</tr>
<tr>
<td>Waxy rice</td>
<td>3.6±1.3a</td>
<td>5.1±0.7b</td>
<td>2.5±1.3a</td>
<td>3.2±0.5a</td>
</tr>
<tr>
<td>Wheat</td>
<td>3.9±1.5a</td>
<td>5.5±0.8ab</td>
<td>2.8±0.9a</td>
<td>3.0±0.6a</td>
</tr>
<tr>
<td>Tapioca</td>
<td>3.6±0.5a</td>
<td>5.7±0.8ab</td>
<td>2.6±0.9a</td>
<td>3.2±0.4a</td>
</tr>
<tr>
<td>Potato</td>
<td>3.1±0.9a</td>
<td>5.8±0.8a</td>
<td>2.3±1.1a</td>
<td>3.1±0.5a</td>
</tr>
</tbody>
</table>

\(^1\)Mean values ± standard deviation with the same letter in the same column are not significantly different \((P > 0.05)\).

\(^2\)Control contains no oxidized starch.
Figure 1-Pasting profiles of native and oxidized starches by Micro ViscoAmyloGraph.
Figure 2—Cold batter viscosity of the control and the oxidized starch formulations.
APPENDIX

LETTER FROM ADVISOR

LETTER FROM PUBLISHER
Nov. 27, 2013

To Whom It May Concern:

This letter is to certify that Sarah Purcell had done at least 51% of the work for a submitted manuscript titled “Application of oxidized starches in bake-only chicken nuggets”.

Sincerely yours,

Ya-Jane Wang, Ph.D.
Professor
Dec. 2, 2013

Dear Ms. Purcell,

We have received the following submissions to the Journal of Food Science: Food Chemistry section: JFDS-2013-1522 “Application of Oxidized Starches in Bake-Only Chicken Nuggets” and JFDS-2013-1481 “Enzyme-Modified Starch as an Oil Delivery System for Bake-Only Chicken Nuggets”, on which you are co-author and Prof. Ya-Jane Wang is corresponding author. Both papers are well into the review process, but we do not yet have enough completed reviews to send you a decision on either one. I think you for your patience.

The Journal of Food Science (JFS) policy allows authors to re-use portions of their own JFS-published work without formal permission, and allows for research from an author’s dissertation or thesis to be published in the journal. We understand that you have included research from these studies in your thesis at the University of Arkansas. This does not present any conflict with publishing these papers in JFS, should they be accepted.

We hope you will continue to submit future work to IFT’s Scientific Journals.

Sincerely,

Amanda Ferguson
Associate Director, IFT Scientific Journals
Institute of Food Technologists
525 W. Van Buren St., Suite 1000
Chicago, IL 60607
aferguson@ift.org
312.806.8088
CHAPTER 5
OVERALL CONCLUSION

This study investigated the use of two modified starches in bake-only nugget formulations. Enzyme modified starches offer a promising structure to deliver oil-based liquids in a dry batter or breading blend. Oil plated starch delivered into a bake-only breading systems shows promise for providing a similar eating experience to the par-fried and baked versions.

Oxidized starches were evaluated in steam-baked nuggets to enhance adhesion property. They resulted in different textural attributes (hardness and crispness), but did not provide improvement in coating adhesion to substrate. Because of the usage of steam and oven baking to replace frying, the results suggest a lower amount of oil was delivered to the customer offering a healthy alternative to the partially fried versions. The nugget preparation method used in this study could be further optimized to target differing nugget profiles. Further investigation is needed to further optimize the formulation of bake-only chicken-nugget products.