Sweet potato starch and a protein-based edible coating minimize the fat-uptake in deep-fat fried chicken

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ABSTRACT

The main objective of this study was to investigate the effectiveness of a newly developed batter containing sweet potato starch and a chicken protein-based edible coating (0, 5, 10, and 15% chicken protein) on fat-uptake reduction in deep-fat fried chicken drumsticks. Results showed that chicken drumsticks with 15% chicken protein-based edible coating and sweet potato starch-based batter had significantly (P < .05) lower fat uptake compared to control. The application of the edible coating did not have any significant influence (P > .05) on pH, color, frying yield, and sensory attributes of the coated chicken samples. Generally, the use of edible coating made the fried chicken samples less hard than the uncoated samples. Thus, this edible coating would provide consumers with healthier food products and utilize by-products generated from chicken processing. Also, using sweet potato starch in the batter system provides an alternative to the conventional battering system, with improved product qualities.

El almidón de camote [boniato] y un recubrimiento comestible a base de proteínas minimizan la absorción de grasa en el pollo frito

RESUMEN

El objetivo principal de este estudio consistió en investigar la eficacia de un nuevo rebozado que contiene almidón de camote y un recubrimiento comestible a base de 0, 5, 10 y 15% proteína de pollo en la reducción de la absorción de grasa por los muslos de pollo fritos. Los resultados dan cuenta de que los muslos de pollo con un recubrimiento comestible a base de 15% de proteína de pollo y un rebozado a base de almidón de camote presentan una absorción de grasa significativamente menor (P<.05) en comparación con el control. La aplicación del recubrimiento comestible no incidió significativamente (P>.05) en el pH, el color, el rendimiento de la fritura y los atributos sensoriales de las muestras de pollo recubiertas. En general, se constató que el uso del recubrimiento comestible hizo que las muestras de pollo frito fueran menos duras que las muestras sin recubrimiento. Ello significa que este recubrimiento comestible podría proporcionar a los consumidores productos alimenticios más saludables, a la vez que utilizaría los subproductos generados durante el procesamiento de pollo. Además, el uso de almidón de camote en el sistema de rebozado proporciona una alternativa al sistema de rebozado convencional, lo que supone una mejora en las cualidades del producto.

Abbreviations: CPI: Chicken processing isolate; HPMC: Hydroxypropyl Methylcellulose; ISP: Isoelectric solubilization/precipitation; ddH2O: distilled deionized.

PALABRAS CLAVE

Revestimiento comestible; pollo frito; absorción de grasa; almidón de camote; rebozado

1. Introduction

Frequent consumption of fried foods has been directly associated with a higher risk of developing chronic diseases such as type 2 diabetes, heart failure, hypertension, and obesity (Ananey-Obiri et al., 2020). Healthcare costs associated with chronic diseases in the United States are estimated to be more than US$3,000 per capita (between US$89 billion and US$212 billion in total costs). The rising rates of chronic diseases are indicative of a public health crisis that demands measures such as changes in the food industry to promote healthier diets (Schneider et al., 2020).

Research into methods of limiting oil uptake during deep-fat frying has led to the discovery of edible coatings. During the processing of chicken meat into new food products, a significant quantity of by-products is produced containing residual meat left on bones, skin, etc. These by-products are normally discarded while they contain nutritious compounds such as proteins (Tahergorabi et al., 2011, 2012). Our previous research showed that meat protein from processing by-products of chicken can be recovered using isoelectric solubilization/precipitation (ISP) and it can be further used to develop edible coatings. Our results indicated that chicken protein-based edible coating can reduce the fat uptake in deep-fat fried chicken up to 60% when compared to uncoated samples (Ananey-Obiri et al., 2020). Also, protein-based edible coatings derived from the chicken have a higher consumer reach, as chicken products are accepted...
in almost all parts of the world and religions. Furthermore, products from animal sources provide essential amino acids and contribute to high amounts of vitamin B12, B6, riboflavin, niacin, phosphorus, and calcium (Ananey-Obiri et al., 2018).

In the foodservice industry, food surfaces are usually coated with batter before frying. Batters are typically composed of starch (normally cornstarch), gum, salt, and a leavening agent. The application of batter to foods offers a crispy deep-fried battered food owning a highly desired flavor. Studies have revealed that battering also plays a crucial role in reducing fat uptake (Zhang et al., 2020). A study by Llorca et al. (2003) shows that modification of the flour significantly alters oil absorption in deep-fat fried battered food. Two major factors are influencing the functionalities of flour and starches, i.e., the size of granules and the amylose content.

The size of granules affects functionalities such as solubility and water-holding capacity (Moorthy et al., 2012). Currently, commercial batters contain mainly cornflour and cornstarch. In general, starches with cereal origins such as cornstarch have lower water-binding capacity than potato starches due to their larger granule size. As a result, cornstarch exhibits lower swelling power, solubility, paste clarity, and viscosity than potato starch (Singh et al., 2003). Sweet potato (Ipomea batatas) is similar to regular potato while it is an excellent source of dietary fiber, minerals, vitamins, and beta carotene and about 80% of the sweet potato is starch. However, its protein content is low (Alotaibi & Tahergorabi, 2018).

The amylopectin content of the cornstarch granules is 70–80% approximately while its amylose content is less than 30% by weight. In contrast, the amylose content of sweet potato starch is slightly lower than those of cornstarch which is about 20% (Issa et al., 2017). The amylose to amylopectin ratio is the key factor that determines the degree to which a starch gelatinizes. Also, potato starches have been acknowledged due to their high resistant starch content which plays a key role in reducing the fat uptake in deep-fat fried foods according to Sánchez-Zapata et al. (2015), while comparatively, cornstarch has much lower resistant starch. Therefore, the main objective of this study was to investigate the potential application of sweet potato starch in the batter system in reducing the fat-uptake of deep-fried chicken as well as studying the synergistic effect of the sweet potato starch-based batter and the protein based edible coating to minimize the fat-uptake.

2. Materials and methods

2.1. Chicken sample processing

Fresh chicken drumsticks, purchased from a local grocery shop, were cut into rectangular slabs of approximately 10 ± 1 g. Trimmings, skins, and meat left on the bone from chicken drumsticks were ground by a 0.5 cm hole diameter meat grinder (LEM grinder, 5 Big Bite Grinder-0.35 HP, West Chester, OH, USA). The ground product was washed and subsequently homogenized with 0.05 M cold NaCl (2–4°C) for 2 min at a speed of 20,784 x g. The mixture was homogenized at a ratio of 1:5 (ground chicken – NaCl w: v) using a laboratory homogenizer (Homogenizer, OMNI International, Kennesaw, GA, USA). A refrigerated centrifuge (Thermo Scientific, Model ST 16 Centrifuge Series, Asheville, NC, USA), set at 4°C and a speed of 5000 x g was used to centrifuge the homogenized samples. The supernatant was removed, and the washed chicken slurry was used for the next step.

2.2. Chicken protein isolation using isoelectric solubilization/precipitation

The protein isolation was performed according to Matak et al. (2015) (Figure 1). Briefly, the washed chicken slurry was homogenized in a 1:6 (w/v) chicken/distilled deionized water (ddH2O) mixture for 5 min. The mixture was

![Figure 1](https://example.com/image1.png)

**Figure 1.** A process flow diagram of isoelectric solubilization/precipitation method for recovering protein from chicken processing by-products and subsequent formulation of edible coating at different protein concentrations.

**Figura 1.** Diagrama de flujo del proceso del método de solubilización/precipitación isoeletrica para la recuperación de proteínas de los subproductos provenientes de la elaboración del pollo y posterior formulación de un recubrimiento comestible con diferentes concentraciones de proteínas.
homogenized at a speed and temperature of 20,784 x g and 4°C, respectively. The pH of the homogenized mixture was adjusted to 11.50 ± 0.05 with a 10 N NaOH solution. The solution was held at this pH for 10 min and centrifuged for 20 min at 5,000 x g and 4°C. The pH of the middle layer containing the chicken protein solution was adjusted with 6 N HCl to the isoelectric point of 5.5 ± 0.05 to precipitate. The solution was left to react for about 10 min and centrifuged for 20 min at 5,000 x g and 4°C. The resultant sediment was collected as chicken protein isolate (CPI) and used to prepare the edible coating. The average fat contents of the washed CPIs used for edible coating were less than 0.02%.

2.3. Preparation of edible coating
In order to make chicken protein-based edible coating with different concentrations of 5, 10, and 15% (w/w); CPI was formulated with water. Glycerol was added at 0.4% (w/w) of the CPI. A 10 N NaOH solution was used to adjust the pH of the mixture to 11 ± 0.05. The mixture was homogenized then, at 20,784 x g for 1 min. The pH of the mixture was re-adjusted to approximately 7 ± 0.05 using 6 N HCl solution.

2.4. Battering and breading
The batter was formulated according to Sahin et al. (2005), with minor modifications. The batter was composed of 48.75% (w/v) wheat flour (King Arthur Flour Company, Inc., Vermont, USA), 48.75% sweet potato starch (New Honda International, Inc., Taichung, Taiwan), 1.0% HPMC (Methocel E15 Premium LV Hydroxypropyl Methylcellulose, Midland, USA), 1.0% salt (Morton, Chicago, USA), 0.5% baking powder (Rumford, Terre Haute, USA), and deionized water. A Stein cup was used to measure the viscosity. Breading was done using plain breadcrumbs (Progresso, breadcrumbs, MN, USA).

2.5. Chicken sample preparation for frying and frying procedure
Chicken pieces were predusted to facilitate absorption of surface moisture for good adhesion of batter. The edible coatings were applied by the method of immersion in either 5%, 10%, or 15% (w/w) protein. The coated samples were gently shaken to remove excess coating. The coated chicken pieces were dipped in batter and gently rolled in breadcrumbs to allow for evenly coating. Sixty g of coated breaded chicken samples and uncoated breaded chicken samples were deep-fat fried in 4-L of canola oil at 177.7°C for 3–4 minutes in a deep fryer (Presto® Dual ProFryTM/1800 W, National Presto Industries Inc., WL., U.S) for each batch. After frying each batch of the chicken samples, the oil was changed. This may reduce the negative impact of oil degradation on the fat uptake of the chicken samples. The fried samples were removed from the oil using prongs and kept on a paper towel to allow them to cool and dry at ambient temperature with natural air.

2.6. Analytical methods
2.6.1. Proximate composition
The method used for fat (Soxhlet extraction method) and moisture analysis of fried chicken samples was according to Association of Official Analytical Chemists (AOAC, 2000a) and AOAC (2000b), respectively. For moisture analysis, about 1–3 g was transferred into an empty pre-weighed dish and dried at 105°C in a vacuum oven. Ash content was determined according to AOAC (1995) by incinerating samples at 550°C for 24 h. The pH was also measured using a pH meter (OMNI International, Kennesaw, GA, USA).

2.6.2. Protein determination of the protein isolate
The protein content of the CPIs was determined using the Bradford method with slight modifications (Bradford, 1976). Thirty ml of 0.1 M NaOH and 3.5% NaCl were added to 0.5 g of the CPIs and homogenized using a laboratory homogenizer (Homogenizer, OMNI International, Kennesaw, GA, USA). After centrifugation at 4000 x g at 4°C for 30, the supernatant was used for protein analysis.

2.6.3. Fat uptake and frying yield
Fat uptake was calculated according to the following formula:

\[
\text{Fat Uptake} (\%) = \frac{w_a - w_b}{w_b} \times 100
\]

where, \(w_a\) is fat content (g) of the sample after frying; \(w_b\) is fat content (g) of the sample before frying.

The percentage frying yield was calculated as a ratio of the weight of the sample after frying to the weight of the sample before frying expressed as a percentage.

2.6.4. Color and texture analyses
Color measurements of the samples were measured using Minolta Chroma Meter CR-400 colorimeter (Minolta Camera Co. Ltd., Japan). The breaking force of samples was assessed by a puncture test using a texture analyzer (Model TA-XT2, Texture Analyzer, Texture Technologies Corp., Scarsdale, NY, USA).

2.6.5. Sensory evaluation
Approval for conducting sensory evaluation was first sought from the institutional review board (IRB). Twenty-five untrained panelists were asked to evaluate color, texture, appearance, and odor using a 9-point hedonic scale. Participants ranked on a scale of 1–9 with 1 = “dislike extremely,” and 9 = “Like extremely”.

2.7. Statistical analysis
The frying experiments and analyses were conducted in triplicates under each experimental condition. The mean values were expressed as results ± standard deviation. All data were assessed by analysis of variance ANOVA (SAS, version 16.0, SAS Institute, Cary, NC) to determine effects at a significance level of \(P < .05\). The calculated mean differences among the treatments were compared using Tukey’s test.

3. Results and discussion
3.1. Fat
The fat content and fat-uptake of the deep-fat fried chicken drumstick samples coated with edible coating and batter containing sweet potato starch are shown in Table 1.
Table 1. Proximate composition of deep-fat fried chicken drumsticks.

| Experimental Treatments | % | Control | 5% CP | 10% CP | 15% CP |
|--------------------------|---|---------|-------|--------|--------|
| Fat uptake               |   | 3.57 ± 0.40<sup>a</sup> | 1.69 ± 0.33<sup>b</sup> | 1.32 ± 0.71<sup>b</sup> | 0.67 ± 0.38<sup>b</sup> |
| Fat content              |   | 12.83 ± 0.29<sup>a</sup> | 10.33 ± 0.58<sup>b</sup> | 9.97 ± 0.16<sup>b</sup> | 5.67 ± 0.38<sup>b</sup> |
| Moisture                 |   | 47.67 ± 1.53<sup>a</sup> | 33.45 ± 4.39<sup>b</sup> | 26.49 ± 2.31<sup>b</sup> | 30.99 ± 1.00<sup>b</sup> |
| Ash                      |   | 1.15 ± 0.04<sup>a</sup> | 0.92 ± 0.24<sup>b</sup> | 1.50 ± 0.41<sup>b</sup> | 0.86 ± 0.31<sup>b</sup> |

Data are given as mean values ± standard deviation. Different letters within the same row indicate significant differences (Tukey’s Test, <i>p < .05</i>) between mean values.

Los datos se presentan como valores medios ± desviación estándar. Las distintas letras dentro de la misma fila indican diferencias significativas (prueba de Tukey, <i>p < .05</i>) entre los valores medios.

Significant reduction (<i>P < .05</i>) in the fat content of the deep-fat fried chicken drumsticks was observed when the edible coatings at different concentrations (5, 10, and 15% chicken protein-CP) were applied to the samples. However, the fat content reduction was more pronounced when the concentration of the protein increased in the edible coating. It appears that edible coating on the surface of the chicken drumsticks forms a barrier that inhibits oil penetration during frying. The protein in edible coating contains myofibrillar protein in which gels due to exposure to high heat during deep-frying. As described by Lesiów and Xiong (2001), the application of heat denatures proteins, leading to an irreversible assembly of myosin heads, finally forming a three-dimensional network. Furthermore, a high protein concentration in edible coatings increases the retardation of fat absorption through the formation of a complex system of molecules (Branan et al., 2014). Also, the method of protein isolation might have contributed to the formation of stronger gelation of the protein in the edible coating. Previously, researchers found that proteins isolated using the alkaline ISP method provide stronger protein gels when heated (Chen & Jaczynski, 2007; Pérez-mateos et al., 2004; Yongsawadilagul & Park, 2004). Undeland et al. (2002) indicated that increased gel strength of alkali-recovered protein during ISP could be due to different conformational changes of protein during protein unfolding and refolding. Stronger and durable gels further inhibit the absorption of oil and retain moisture during deep-frying. Also, the use of sodium chloride in the washing of the muscle in this study might have enhanced the gel-forming ability of the chicken protein during heating, as reported by Sun and Armfield (2011).

Using only 5% CP in the edible coating reduced fat uptake up to more than 52% in sweet potato starch-based battered samples in this study. However, Dragich and Krochta (2010) obtained 30.68% fat uptake reduction in wheat-flour-battered chicken strips coated with 10% wheat protein which is lower than the fat uptake reduction in our study. A 10% whey protein as a postbreading dip also reduced oil uptake by 37% in patties (Branan & Pettit, 2015), which is still lower than 5% CP in this study. In our previous study, when cornstarch was used in batter formulation, fat uptake was recorded at 2.86%, 1.96%, and 1.77% for 5%, 10%, and 15% CP, respectively (Ananey-Obiri et al., 2020) whereas in the current study, 5%, 10%, and 15% CP and batter containing sweet potato starch showed fat uptake reduction values as 1.69%, 1.32%, 0.67%, respectively, which comparatively shows that sweet potato starch is more effective in reducing the fat uptake in deep-fat fried chicken. Also, frying induces the gelatinization of starch in batter, resulting in the formation of strong, disordered and brittle films formed by the amylose content (Zobel, 1988). The higher amylose content in cornstarch than sweet potato starch may form stronger gels with smaller pores than sweet potato starch. The comparatively smaller pores formed by the cornstarch may promote the uptake of oil once the fried chicken is removed from the oil due to the sudden drop of positive vapor pressure causing surface oil to drip into the chicken (Dana & Saguy, 2006). This resultanty may have increased the total lipid content in cornstarch battered deep-fried chickens compared to sweet potato starch battered samples.

Gelatinization is characterized by the breaking of hydrogen bonds, loss of orderliness of starch granules, and the subsequent swelling of granules. The amylose content leaves out of the granules, creating a void in the starch granule. Amylose leach more easily from cornstarch than in potato starch (Bertoft, 2017). The differential higher amount of amylose (30%) in cornstarch than in sweet potato (20%) starch presupposes that more space will be created in the cornstarch than the sweet potato starch. Also, amylose can trap many lipid molecules (Le-Bail et al., 2018). The relatively larger void created in cornstarch than in sweet potato starch due to the difference in amylose content could have led to more oil being trapped in cornstarch battered fried samples. Similarly, resistant starch plays an important role in fat uptake reduction during frying. According to Sánchez-Zapata et al. (2015), resistant starch helps reduce uptake in deep-fried foods. Sweet potato starch by percentage, has a higher resistant starch concentration than cornstarch. Therefore, the higher amount of resistant starch in sweet potato starch could have contributed to the lower fat content of the fried samples.

### 3.2. Moisture

The moisture content of the deep-fried samples is shown in Table 1. The characteristic contents of deep-fat fried foods could be related to their moisture content. In general, the control sample lost the highest moisture content when compared to coated samples. The protein-based edible coating containing 10% protein retained the highest amount of moisture amongst the other coated samples but did not change significantly (<i>P > .05</i>) from other treatments, except control samples. Studies show that the application of the edible coating on deep-fat fried foods inhibits moisture loss and reduces fat absorption (De Grandi Castro Freitas et al., 2009). The network formed by the edible coating prevented the moisture from escaping, thus, retaining higher moisture content in coated samples than the uncoated samples (controls).

The water loss mechanism is one of the mechanisms that is used to explain the fat uptake and subsequent moisture loss in deep-fat fried foods. According to this theory, there is an inverse relationship between fat uptake and moisture loss in deep-fat fried foods. However, we did not observe this trend in our samples which means treatments with a high amount of moisture did not produce a corresponding fat uptake reduction. Similarly, Ouchon et al. (2003) could not find a regular pattern between moisture loss and fat absorption during frying. It can be explained by the mechanism that oil absorption during frying is a surface phenomenon...
involving equilibrium oil adhesion and drainage upon removal from the oil (Ufheil & Escher, 1996).

Fried chicken samples with 15% CP and cornstarch batter retained higher (57%) moisture content in the study conducted by Ananey-Obiri et al. (2020), while samples dipped in batter containing sweet potato starch before frying retained a lower amount of moisture (50%) than the cornstarch batter samples in this study. During frying, amylose in the starch forms a gel and coats the food. High amylose content can form strong and flexible films apparently due to the crystallization of amylose (And & Han, 2005). The films act as a barrier to moisture loss during frying of the samples. Consequently, the stronger films formed in cornstarch samples will block moisture from escaping than as in sweet potato starch samples.

3.3. Ash

Table 1 also describes the ash content of uncoated samples and coated samples. The results reveal no statistically significant difference in values between all treatments (P > .05). However, 15% of CP coated samples recorded the lowest ash content. The highest ash content (1.50 ± 0.41) was obtained in chicken samples coated with 10% CP.

3.4. Color

The color values of uncoated and coated deep-fried chicken are shown in Table 2. Tristimulus color values of all different concentrations of edible coated samples were not significantly different (P > .05) from control samples. Additionally, increasing the concentration of the protein in edible coating or using sweet potato starch-based batter did not alter the tristimulus color values including L*, a*, and b*.

3.5. Puncture test

Figure 2 shows the maximum peak puncture forces of deep-fat fried chicken. The texture of the food is one of the key factors in consumer preferences and purchasing decisions, particularly for foods with semi-solid or solid textures (Pascua et al., 2013). Puncture test is usually used to evaluate the fracture properties of foods with crust and also produces results relating to mastication in foods. The puncture test indicates the hardness of the samples. Hardness describes the forces (N) needed to attain a deformation in a sample (Nishinari & Fang, 2018).

No significant differences (P > .05) were observed between control and samples coated with 5% and 10% CP. However, the lowest puncture force which also indicates the softest sample was found in deep-fat fried samples coated with 15% CP (P < .05). Similarly, Rayner et al. (2000), reported that when they coated their samples with 10% soy protein, the coated samples were significantly softer than uncoated fried samples. The softness of the coated samples could be due to their higher moisture content in comparison with uncoated samples (control). In general, higher moisture content increases the juiciness and tenderness of the product which favors consumers (Myers & Brannan, 2012). Similarly, the formation of softer crust can be ascribed to the edible coating (Izadi et al., 2015). A study by Ross and Porter (1976) attributed this occurrence to the redistribution of moisture after frying, causing softening of the crust and subsequently, a lower shear force value. Comparable to a study by Mah and Brannan (2009), no significant difference was observed between the texture of 2.5%, 5.0%, and 10.0% whey protein isolate coated and uncoated battered and breaded deep-fried chicken patties.

3.6. pH

The pH values reported, as shown in Figure 3, do not reveal any significant differences among treatments. Thus, the pH.
was not influenced by the application of the edible coating. This could be because the pH of the edible coating was adjusted to neutral. Sweet potato starch-based batter did not alter the pH of the fried foods. This result indicates that replacing cornstarch with sweet potato starch in batter formulation does not affect the pH of the fried samples.

### 3.7. Frying yield

Cooking loss results from the evaporation of moisture and dripping of oil from the product after cooking (Küçüköz et al., 2018). Cooking loss is inversely proportional to frying yield. Figure 4 shows no significant difference in frying yield among all treatments ($P > .05$). Even though there were no significant frying yield differences among the various treatments ($P < .05$), CP samples experienced the lowest cooking loss. The highest frying yield was found in 15% CP coated deep-fat fried samples, followed by 10% CP samples. This could be as a consequence of the development of films by the proteins in the edible coatings, hence, retaining water within the food product (Karimi & Kenari, 2016). Also, the chicken protein gelation due to heat exposure in the edible coating acted as a barrier to maintain and decrease the loss of mass during frying. This suggests that the total net mass transfer during the frying process was similar in both coated and uncoated samples.

### 3.8. Sensory properties

Table 3 displays the sensory evaluation scores of attributes of deep-fat fried samples. The score of all sensory attributes of edible coated deep-fat fried samples ranged from 7.0 to 8.3, slightly higher than the score of the controls, which was between 6.6 and 7.2. The scores for all sensory attributes for all treatments (both controls and coated) were not significantly different ($P > .05$). However, almost all edible coated samples received higher scores in all attributes than the controls. Coated samples received more “like very much” scores than the controls.

### 4. Conclusions

All chicken drumsticks coated with an edible coating at the three different levels of protein (5, 10, and 15% w/w) and dipped in batter containing sweet potato starch had significantly lower ($P < .05$) oil content and fat-uptake than all
controls. Increasing protein concentration in the edible coating produced a corresponding fat-uptake reduction in fried samples; using sweet potato starch in the batter along with protein coating at 15% w/w component produced fried samples with the lowest oil content and fat-uptake, improved texture, color than the control sample. The sensory properties such as color, texture, odor, the appearance of deep-fat fried chicken samples were not negatively affected when coated with the protein-based edible coating or sweet potato starch in the batter.

**Data availability statement**

The data are available within this manuscript.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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