

Adhesion of Rice Flour-Based Batter to Chicken Drumsticks Evaluated by Laser Scanning Confocal Microscopy and Texture Analysis

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ABSTRACT The convenience and appeal of battered or breaded products have resulted in a sales increase of 100% since 1980. Because of the rapid growth of the Asian-American population and increasing consumption of rice and rice products, rice flour is a logical alternative for wheat flour in traditional batter formulation.

The effects of ingredients used in rice flour-based batters on adhesion characteristic for deep-fat fried chicken drumsticks were studied by laser scanning confocal microscopy (LSCM) and texture analysis. Raw chicken drumsticks were predested with egg albumin powder before dipping into batters prepared from combinations of rice flour, yellow corn flour, oxidized cornstarch, methylcellulose, or xanthan gum. The drumsticks were fried at 175 ± 5 C until the internal temperature reached at least 71 C. For LSCM, samples were fixed overnight and were sectioned by vibratome (200 μ m) before viewing.

(Key words: rice, chicken drumstick, batter, adhesion, microscopy)

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INTRODUCTION

Battered and breaded foods represent a fast-growing category in most high-convenience consumer societies such as the United States (Shukla, 1993). The per capita consumption of battered and breaded foods in the United States has increased from less than 2.27 kg in 1982 to 6.82 kg in 1992, and the annual volume of formulated batters and breadings is about 52×10^7 kg. The consumption of battered and breaded products in Europe, Japan, Oceania, and other Pacific Rim countries is approximately 91×10^7 kg (Shukla, 1993). Additionally, battered and breaded foods are very common in developing countries. The trend of using batter and breading on chicken has increased remarkably since the 1980s, and such products constitute the largest segment of the further-processed poultry market (Parinyasiri and Chen, 1992). The annual sales of fried chicken are estimated to be more than \$6

Batter adhesion was determined using an attachment specifically designed for chicken drumsticks.

Microstructural analysis showed that batter formulated with a 50:50 mixture of rice and corn flours adhered better to drumsticks than batter with other rice flour ratios. Xanthan gum (0.2%) or methylcellulose (0.3%) alone had poor adhesion to chicken skin. However, when combined with other ingredients, xanthan gum increased the amount of batter pick-up before frying by increasing viscosity. Egg albumin significantly facilitated batter adhesion. The results from texture analysis supported the microstructural studies. As rice flour ratio increased from 50 to 70%, the binding force decreased. Rice flour showed potential as an alternative to wheat flour for batter formulas when the appropriate levels of oxidized starch, xanthan gum, and methylcellulose were included in the formulation.

billion in the United States (Mohan Rao and Delaney, 1995).

Traditionally, wheat flour is the major ingredient used in batter formulation (30 to 50%; Loewe, 1993). However, wheat flour is an expensive ingredient in Asia, where rice is a staple crop. Thus, rice flour could serve as an alternative to wheat flour in battered and breaded foods. Rice flour-based batter (RFB) might be a commercially feasible new product for the United States food industry, because it would have an international appeal to the Asian-American market. Among minorities in the United States, the Asian-American population has increased by 31%, which may cause a market shift (Sloan, 1999). The USA Rice Federation (1997) reported that consumption of rice, particularly processed foods made from rice in the United States, has increased significantly between 1980 to 1982 and 1995 to 1996. The trend of rice consumption per capita in the United States is expected to continue to

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Abbreviation Key: LSCM = laser scanning confocal microscopy; RFB = rice flour-based batter; SEM = scanning electron microscope; WFB = wheat flour-based batter.

increase with the growth of the Asian-American and Hispanic-American populations, the popularity of ethnic cuisines, and a national obsession for eating light and healthy. The United States rice market for rice and rice products was estimated to have 5 to 6% annual increase and reach nearly \$2 billion by 1999 (USA Rice Federation, 1997).

Additionally, RFB formulations would add value to rice and serve as an alternative for individuals with gluten allergies, because rice is less allergenic than other grain flours. Potentially, RFB would be a healthy alternative providing fewer calories. Shih and Daigle (1999) found that the proteins and starch in rice flour are chemically different from those in wheat flour. They reported that RFB absorbed substantially less oil than wheat flour-based batter (WFB). Rice is high in prolamin (Juliano, 1992), whereas gluten proteins in wheat are very high in glutamic acids and proline (about 35 and 14% of the total protein, respectively; Hosoney, 1994).

In a batter system, adhesion is the chemical and physical bonding of a food coating, both with itself and with the food product (Suderman and Cunningham, 1983). Adhesion is a critical characteristic for battered products. Factors affecting adhesion of batter to food products are properties of the food used (Suderman and Cunningham, 1977, 1980), batter ingredients (Hanson and Fletcher, 1963; Hale and Goodwin, 1968; Baker et al., 1972a), and cooking methods (Hale and Goodwin, 1968; Baker et al., 1972b).

Basically, poultry skin consists of two layers, the epidermis and the dermis. The epidermis can be subdivided into the stratum corneum (cuticle), stratum granulosum (transitivum), stratum spinosum, and stratum germinativum (stratum basale), going from superficial to deep layers, respectively. The dermis layer is below the epidermis and comprises connective tissue (Lucas and Stettenheim, 1972). The epidermis plays a critical role in batter adhesion because it interfaces with the batter. The cohesive forces among cells within the epidermis and dermis also may affect batter adhesion (Suderman and Cunningham, 1980).

Suderman and Cunningham (1980) investigated the effects of age, method of chilling, and scald temperature on batter adhesion to poultry skin by using a scanning electron microscope (SEM). They reported that the adhesion of batter and breading could be affected by the ultrastructure of poultry skin.

The SEM might be a useful tool for visually evaluating the physical adhesion of batter to chicken skin; however, it requires extensive sample preparation of fixing, dehydration, and sputter-coating (Brooker, 1995). More extensive sample preparation can lead to artifacts in the sample. In contrast, sample preparation and artifacts associated

with sample preparation can be minimized by using laser scanning confocal microscopy (LSCM) (Mutsumoto, 1993). Samples can be viewed directly or with minimal sectioning or fixation procedures. White light or a narrow range of wavelengths of laser light are used to image and excite specific fluorescence material. The LSCM technique allows for thin sectioning (approximately 0.5 μm thick) of a thick sample, which provides 100 times greater signal-to-background ratio than fluorescence microscopy (Vodovotz et al., 1996). The LSCM has been applied in some food research on materials such as cereals (Yui, 1993), emulsions, and dairy products (Brooker, 1991, Blonk and van Aalst, 1993).

In addition to microscopy, batter adhesion could be determined by texture analysis. According to Szczesniak (1963), adhesiveness is "the work necessary to overcome the attractive forces between the surface of the food and the surface of other materials with which the food comes in contact (e.g., tongue, teeth, palate, etc.), so adhesiveness is related to surface properties." Bourne (1978) modified the definition of parameters used in texture analysis by Instron. He defined adhesiveness as "the negative force area for the first bite, representing the work necessary to pull the plunger away from the food samples." Patil et al. (1990) replaced the classical definition of adhesiveness with the term adhesive force, meaning "the maximum negative force obtained in the adhesion area."

The most recently published method for measuring batter adhesion (Suderman and Cunningham, 1979) involved placing a breaded product on a standard wire sieve in a portable sieve shaker. The percentage of bread crumbs that fell off the substrate after shaking the sieve for 1 min was calculated. However, this technique might not directly reflect adhesion between batter and the food interface. A universal objective test that is simple and provides accurate measuring is not currently available.

Batter formulated with rice flour alone would produce an inferior product quality because of the absence of gluten, which contributes to the traditional texture associated with battered products. However, in combination with other food ingredients, including modified starch or gums, rice flour may be an alternative to wheat flour.

The objectives of this study were to compare the effects of ingredients used in RFB on batter adhesion for deep-fat fried chicken drumsticks by visual analysis using an LSCM and texture analysis using a new attachment specifically designed for measuring adhesive force between batter and chicken drumsticks.

MATERIALS AND METHODS

Batter Ingredients and Formulations

Batters were formulated with rice flour RL-100² and yellow corn flour³ (50:50, 60:40, or 70:30), oxidized cornstarch⁴ (0, 5, or 15%), and methylcellulose⁵ (0 or 0.3%). Other ingredients included 2.5% salt, 2% sucrose, and 0.2% xanthan gum.⁶ To compensate for the increases in oxidized starch and methylcellulose in the formulations,

²Riviana Foods Inc., Houston, TX 77252.

³ADM Milling Co., Lincoln, NE 68501.

⁴National Starch and Chemical Co., Bridgewater, NJ 08807.

⁵Dow Chemical Co., Midland, MI 48647.

⁶Jungbunzlauer Inc., Newton Center, MA 02159.

the percentage of flour was reduced while keeping the desired flour ratio constant. The solid to water ratio of batters was 1:1.3 (wt/wt). Batters were mixed at low speed for 3 min in a stainless-steel bowl Model K-45 mixer⁷ and cooled to 10 C for optimum batter application (Suderman, 1990).

Sample Preparation

Frozen chicken drumsticks ranging in weight from 100 to 120 g/piece obtained from a local retail store⁸ were thawed overnight at 4 C. Individual drumsticks were placed in a plastic bag and predusted for 10 s with 1.3 g egg white powder type P-110.⁹ The adhesion characteristics of xanthan gum, methylcellulose, and modified cornstarch were examined by preparation of solutions at the same levels used in batter formulation. The drumsticks, either predusted or not, were dipped into individual ingredient solutions or batters. The excess batter or solution was allowed to drip off for 10 s before deep-fat frying with canola oil at 175 ± 5 C until the internal temperature of drumsticks reached at least 71 C (USDA, 1999), as recorded by a meat thermometer. Then drumsticks were cooled to room temperature.

Sample Preparation for LSCM

Pieces of fried sample were cut into 1-mm³ cubes and fixed overnight at 4 C in a solution of 2% (vol/vol) paraformaldehyde and 2% (vol/vol) glutaraldehyde (Karnovsky's fixative).¹⁰ Fixed tissues were glued (cyanoacrylamide) on a metal block and covered with 2.5% agar to stabilize samples before being sectioned into 200- μ m thicknesses with a vibratome (series 1000).¹¹ Samples were viewed on a laser scanning confocal microscope (model 410)¹² equipped with an Axiovert 100 inverted microscope, an argon-krypton 488/568/647 laser, Ft 488/568 Dichromic beam splitter, KP 600 line selection filter, and BP 515-565 emission filter. The software package LSCM version 3.91 was used for image analysis. Digital image files in tagged-image file format were imported into Adobe Photoshop (version 4.0)¹³ for labeling and adjustments of image size, brightness, and contrast before printing on a dye-sublimating printer (model CP 210U).¹⁴

Measurement of Batter Binding Property

A new attachment probe for measuring adhesive force was developed at Kansas State University.¹⁵ The attach-

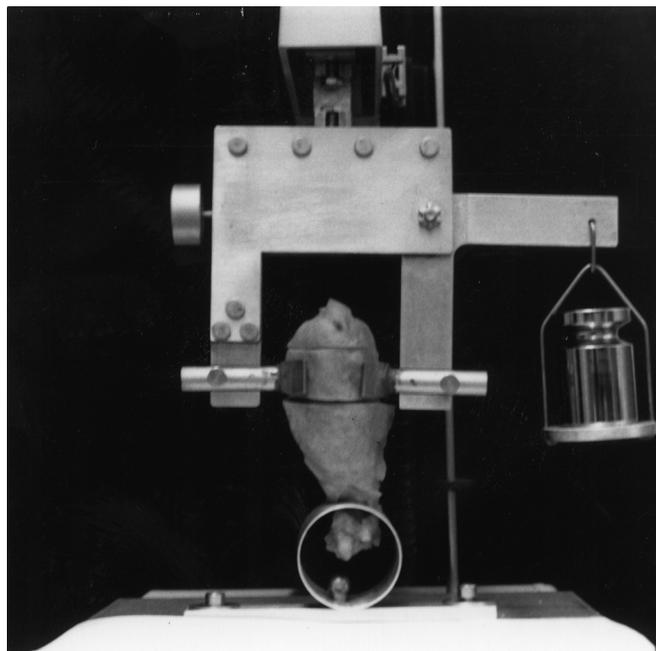


FIGURE 1. An attachment for texture analyzer specifically designed to measure adhesion characteristic of battered, fried chicken drumsticks.

ment probe comprises a metal base for holding a drumstick joint and two grips that connect to a counter balance. The grips can be adjusted to fit each individual drumstick. The amount of tension force in Newtons (1 g mass exerts 9.81 N) needed to pull a 2.5 cm wide section of fried batter off the drumsticks within 80 mm was measured using a TA.XT2 texture analyzer¹⁶ (Figure 1).

Statistical Analysis

For adhesive force measurements, all batter treatments were prepared and tested in triplicate. Statistical analyses were performed using the general linear models procedure to determine the effects of rice flour, starch, and methylcellulose levels on forces needed to separate batter from chicken drumsticks. Least significant difference was used to detect differences among means at $P < 0.05$ (SAS Institute, 1988).

RESULTS AND DISCUSSION

LSCM Analysis

Figure 2 is a representative LSCM micrograph depicting the general microstructure of battered chicken drumsticks. Autofluorescence of chicken and batter components after processing allows for the differentiation of batter, albumin, epidermis, and dermis.

Effect of Hydrocolloids. Micrographs of 0.2% xanthan solution did not show any film adhered to the chicken epidermis (Figure 3). Xanthan gum is a nongelling gum (Hwang and Kokini, 1991), which typically is used to control batter viscosity rather than improve adhesion. Xanthan gum contributes to good suspension (Challen,

⁷Kitchenaid Division, Hobart Co., Troy, OH 45374.

⁸Dillons, Manhattan, KS 66502.

⁹Henningsen Foods Inc., Omaha, NE 68144.

¹⁰EMS, Ft. Washington, PA 19034.

¹¹TED PELLA, Inc., CA 96049.

¹²Carl Zeiss, Inc., Thornwood, NY 10594.

¹³Adobe System, Mountain View, CA 94039.

¹⁴Mitsubishi Electric Sales America, Inc., Cypress, CA 90630.

¹⁵Manhattan, KS 66506.

¹⁶Texture Technologies Co., Scarsdale, NY 10583.

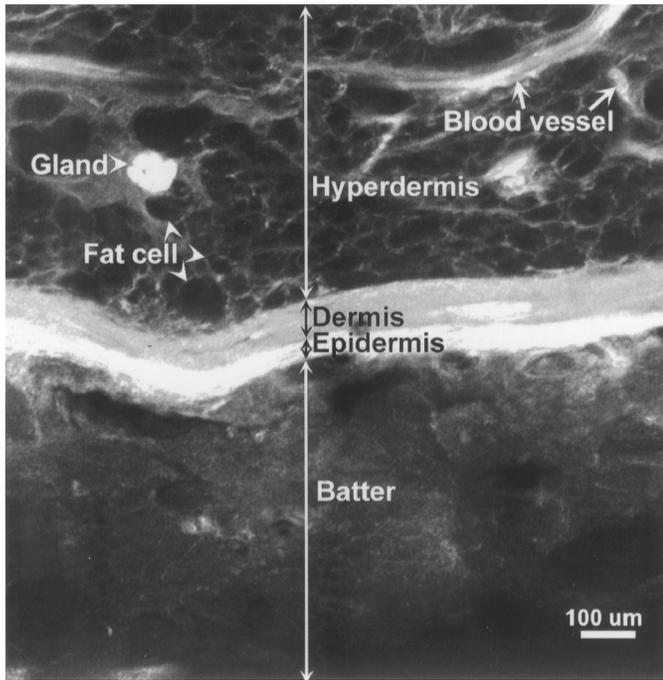


FIGURE 2. Microstructure of fried chicken drumsticks with rice flour-based batter visualized by laser scanning confocal microscopy.



FIGURE 3. Laser scanning confocal micrograph of 0.2% xanthan solution on chicken skin. EP = epidermis.

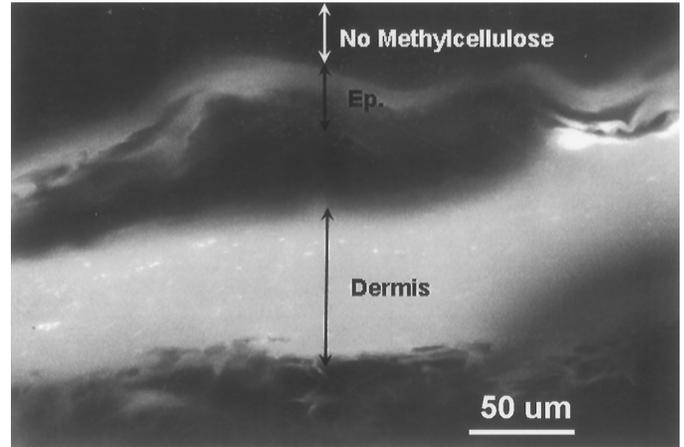


FIGURE 4. Laser scanning confocal micrograph of 0.3% methylcellulose solution on chicken skin. EP = epidermis.

1993) and viscosity stability at elevated temperature and over a wide pH range (Cottrell et al., 1980). Xanthan gum can be used at low concentration to adjust batter viscosity and to maintain a homogeneous suspension (Suderman et al., 1981; David, 1983; Meyers, 1990). However, if used at more than 0.2%, xanthan gum will impart an adverse effect on product quality such as a chewy texture (Kuntz, 1995).

The 0.3% methylcellulose solution did not exhibit any film formation that could be observed by LSCM (Figure 4). Theoretically, methylcellulose can form a thermal gel when heated (Sakar, 1979). A 2% methylcellulose solution showed superior film-forming capability on a glass slide compared to carboxy methylcellulose and xanthan gum (Dow Chemical, 1996). A methylcellulose film that is tough and flexible (Krumel and Lindsay, 1976) can be used as a film former for coating nuts and pretzels (Ward and Andon, 1993). However, in this study methylcellulose used singly did not form gel with battered, fried chicken drumsticks. The legal limit of methylcellulose (Methocel A) allowed in meat and poultry battered-products may not exceed 0.15% on a total battered-product basis (Dow Chemical, 1990). The typically recommended level for methylcellulose applied in meat, poultry, and seafood batter is approximately 0.2 to 0.5% wet batter weight (Dow Chemical, 1993). Within this limit, our results did not support methylcellulose functioning as an adhesive agent to chicken epidermis.

In contrast to xanthan gum and methylcellulose, oxidized cornstarch formed a film on chicken epidermis and muscle (Figure 5). Starches exhibit film formation because of the linear structure of amylose (Wurzburg, 1987). The ratio of amylose to amylopectin in starch determines the film properties. Starch films become weaker with the increase of amylopectin (Young, 1984). In batters for breaded products, modified high amylose starch is used to form a film that prevents moisture migration (Langan, 1987). High amylose starches also seem to keep the coating intact because they impart good bonding between the coating and the substrate. However, coating with a high

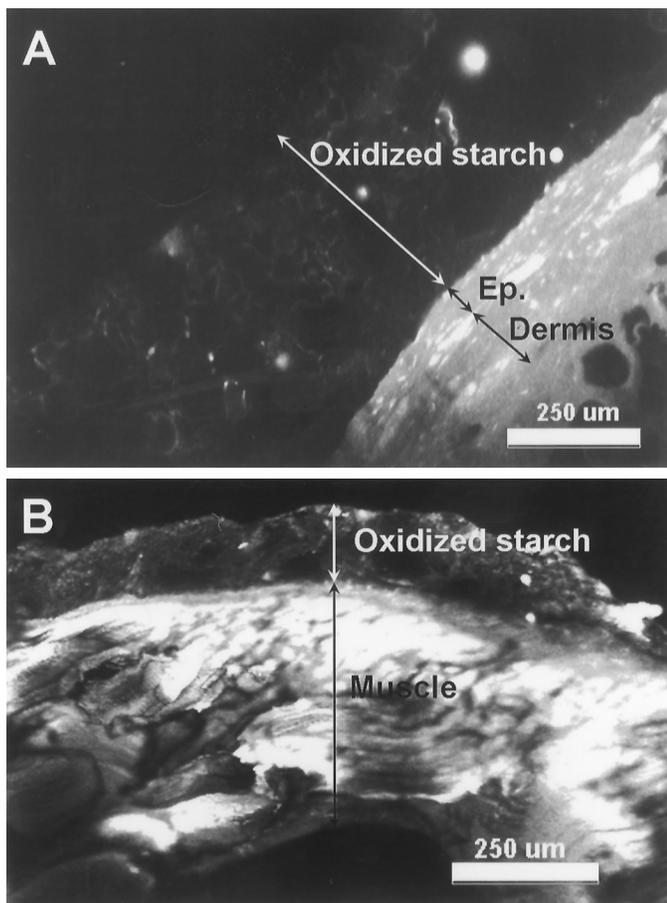


FIGURE 5. Laser scanning confocal micrograph of 5% oxidized corn-starch solution on chicken skin (a) and muscle (b). EP = epidermis.

level of starch yields a rougher surface that is brittle and can flake off (Kuntz, 1995). Hypochlorite-oxidized starch forms a tough, clear, and continuous film (Wurzburg, 1987). Hypochlorite starch tends to be homogeneous, have less tendency to shrink and crack, and be more water soluble compared with films of acid-modified starch or unmodified starch because of an increase in hydrophilic carboxyl groups in the starch molecules (Wurzburg, 1987).

Effect of Albumin. When albumin was used as a pre-dust, a rough surface layer on the chicken epidermis was observed (Figure 6) and potentially facilitated the adhesion of batter components to the drumsticks. In theory, the bond strength between the coating and a smooth surface should not be as strong as that between the coating and a rough surface (Suderman and Cunningham, 1980). A rigid structure formed by albumin when heated will physically adhere the batter to the chicken skin. Egg albumin starts to coagulate at about 62 C and becomes very firm at temperatures greater than 70 C (Endres and Monagle, 1987). When heated, amino residues of albumin undergo hydrophobic aggregation, resulting in denaturation and random association of peptides to form gel networks. Siegel et al. (1979) used SEM to investigate the ultrastructure of nonmeat protein gels as related to their ability to bind meat pieces. They found that egg white

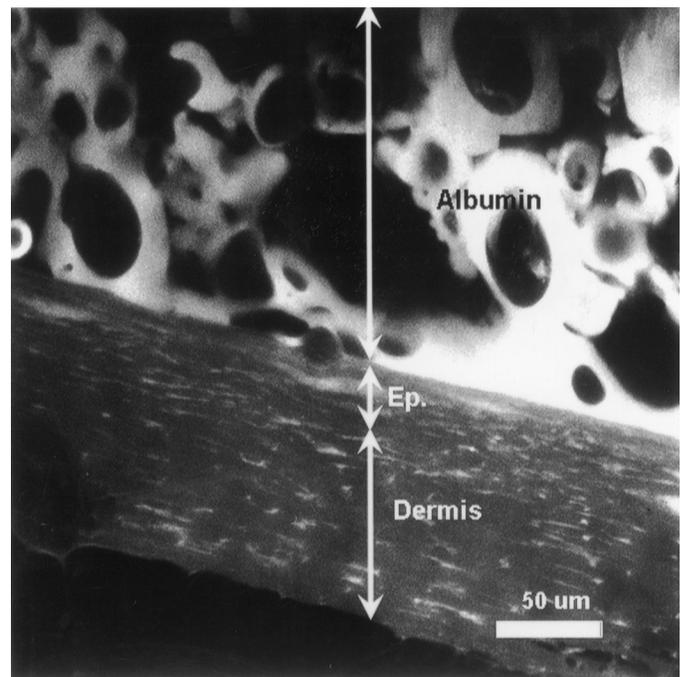


FIGURE 6. Laser scanning confocal micrograph of a porous gel network formed by egg albumin pre-dust adhering to chicken epidermis. EP = epidermis.

formed a three-dimensional network that could bind water and became more porous with the addition of salt and phosphate, thus enhancing water-binding capacity.

In addition to facilitating batter adhesion by absorbing water on the surface of chicken skin, providing a rough surface, and forming a gel network, albumin appeared to enhance batter adhesion by binding with chicken muscle (Figure 7). This binding could occur at the part of drumsticks uncovered by the skin. In an RFB system, such binding might be explained by a process described by Siegel et al. (1979). They reported that egg white with salt allowed binding in meat pieces because it did not interfere with the interaction between myosin molecules appearing at the surface of meat pieces. Furthermore, types of molecular interactions that stabilized the salted egg white gel and myosin gel were most likely the same.

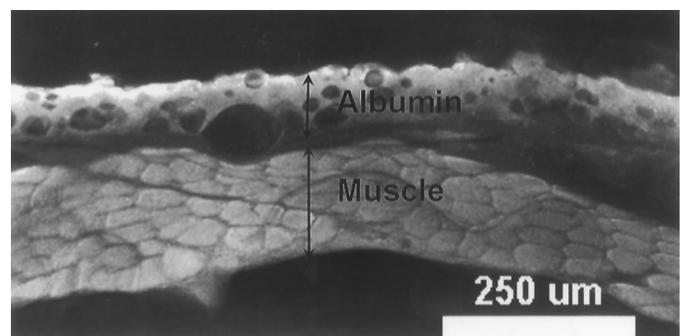


FIGURE 7. A porous albumin gel network adhering to chicken muscle.

TABLE 1. Effects of rice flour, modified starch, and methylcellulose levels on binding force between batters and chicken drumsticks

| Factor | Level (%) | Force (Newtons) |
|--------------------------------|-----------|--------------------|
| Rice flour to corn flour ratio | 50:50 | 10.20 ^a |
| | 60:40 | 10.16 ^a |
| | 70:30 | 9.09 ^b |
| Oxidized cornstarch | 0 | 9.46 ^b |
| | 5 | 9.67 ^b |
| | 15 | 10.31 ^a |
| Methylcellulose | 0 | 9.70 ^a |
| | 0.3 | 9.93 ^a |

^{a,b}Means with different superscripts within a factor are significantly different ($P < 0.05$).

Texture Analysis

Overall, the results from texture analysis with an attachment developed specifically for chicken drumsticks exhibited the same trends observed from LSCM analysis.

Effect of Rice Flour. In this study, the force needed to pull the fried batter off the chicken drumstick implies binding strength between batter and chicken skin. If the binding between batter and skin is strong, a high force would be expected. The average force for 50% RFB (10.20 N) was not significantly different from that for 60% RFB (10.16 N; Table 1). In contrast, the force decreased significantly as rice flour level increased to 70% (9.09 N). The microscopy results also supported this finding. The 70% RFB provided a rough and fragile film that separated more easily from the chicken skin during sectioning. Shih and Daigle (1999) also reported that RFB did not always adhere to chicken breast nuggets.

Effect of Oxidized Cornstarch. No significant difference occurred between the amounts of force necessary to separate the batter from the chicken skin for RFB without oxidized cornstarch and with the addition of 5% of oxidized cornstarch ($P < 0.05$). However, 5% oxidized cornstarch formed a film clearly visualized by LSCM. The force for 50% RFB without oxidized cornstarch was 9.46 N, whereas that for 5% oxidized cornstarch batter was 9.67 N (Table 1). In contrast, the force increased significantly at 15% oxidized cornstarch (10.31 N).

Our results suggested that stronger binding occurred between RFB and chicken skin with the addition of oxi-

dized starch, which improved adhesion by forming covalent and noncovalent bonds. The aldehyde groups of oxidized starch may react with the free amino group of the protein and the hydroxy group of the starch in the batter (Seib and Maningat, 1989). Langan (1987) also reported that oxidized starch was used to improve adhesion of starch batters to fish and meat as well as with breaded products. Commercially, oxidized starches are used widely in batter and breading for poultry and seafoods for special textural properties (Luallen, 1988).

Effect of Methylcellulose. No significant differences in binding were found between treatments with or without methylcellulose from texture analysis (Table 1). This result was consistent with LSCM observations that methylcellulose at a concentration of 0.3% did not form an adherent film to chicken skin. However, methylcellulose may still be of use in batter formulation. Methylcellulose might assist in binding batter ingredients by forming a thermal gel upon frying. This conclusion is supported by findings that methylcellulose alone has been used to bind meat pieces together (Bernal and Stanley, 1989). These results showed that the ability of methylcellulose to be a binder for reformed beef was comparable to that of sodium alginate. Sodium alginate needs calcium to form a stable gel, whereas methylcellulose does not need salt; thus, methylcellulose application in industry would be more practical. Generally, the mechanism involves heat-induced gel formation of binder through the interaction of salt-extracted myofibrillar proteins present at the meat particle interface (Schmidt and Trout, 1984).

We suggested that the effect of methylcellulose on binding property would vary, depending on the nature of product. The effect of methylcellulose on binding might be more pronounced in homogeneous systems, such as reformed meat emulsion, than in batter systems. For batter applied to chicken drumsticks, the effect of methylcellulose might not be as obvious because of their high moisture content. Langan (1988) reported that some gums (no specific gum mentioned) actually might inhibit adhesive strength of batter by excessive binding of water. Excessive bound water causes a steam pressure buildup between batter and substrates, thereby affecting the batter adhesion. Methylcellulose has the ability to absorb water up to 40 times its weight (Glickman, 1969). This water might

TABLE 2. Force needed to pull selected batters off fried chicken drumsticks using an attachment developed for TA.XT2¹

| Treatment ² | Force ³ (Newtons) | Treatment | Force (Newtons) | Treatment | Force (Newtons) |
|------------------------|---------------------------------|-----------|--------------------|-----------|--------------------|
| 5R0S0M | 9.68 ± 0.11 | 5R5S0M | 9.45 ± 1.29 | 5R15S0M | 10.99 ± 1.21 |
| 5R0S3M | 9.45 ± 1.19 | 5R5S3M | 10.15 ± 1.43 | 5R15S3M | 11.45 ± 1.11 |
| 6R0S0M | 9.13 ± 1.06 | 6R5S0M | 9.35 ± 0.51 | 6R15S0M | 11.22 ± 0.28 |
| 6R0S3M | 10.42 ± 0.75 | 6R5S3M | 11.27 ± 0.77 | 6R15S3M | 9.54 ± 0.93 |
| 7R0S0M | 8.83 ± 0.62 | 7R5S0M | 9.40 ± 0.20 | 7R15S0M | 9.21 ± 0.98 |
| 7R0S3M | 9.24 ± 0.38 | 7R5S3M | 8.38 ± 1.25 | 7R15S3M | 9.46 ± 1.25 |

¹Least significant difference = 1.565; SEM = 0.545.

²R = Rice to corn flour [5R is 50:50%; 6R is 60:40%; and 7R is 70:30% (wt/wt)]. S = Oxidized corn starch levels [S0 is 0%; S5 is 5%; and S15 is 15% (dry basis)]. M = Methylcellulose levels [0M is 0%; and 3M is 0.3% (dry basis)].

³Means of three replicates ± SD.

weaken the binding between the batter and chicken drumsticks.

Effects of Batter-Ingredient Interaction. The combination and concentrations of oxidized cornstarch, xanthan gum, and methylcellulose used in the RFB in this study significantly improved the binding force between the batter and chicken drumsticks ($P < 0.05$) as determined by texture analysis. However, a synergistic effect between rice flour and the hydrocolloids depended on rice flour levels. The force for 50% RFB without any hydrocolloids was 9.68 N. The addition of 15% oxidized cornstarch and 0.3% methylcellulose to 50% RFB increased the force to 11.45 N (Table 2). For 60% RFB alone, the force was significantly different from that for 60% RFB with 5% oxidized cornstarch and 0.3% methylcellulose or for 60% RFB with 15% oxidized cornstarch and no methylcellulose, showing an interaction among ingredients. In contrast, no significant difference occurred for 70% RFB in absence or presence of hydrocolloids. High binding forces were found for 15% oxidized cornstarch with 0.3% methylcellulose and 50% RFB, for 60% RFB with 5% oxidized cornstarch and 0.3% methylcellulose, and for 60% RFB with 15% oxidized cornstarch and 0% methylcellulose, which were not significantly different from each other. This result suggested that a batter containing 50% rice and corn flours needed a high level of oxidized cornstarch and methylcellulose, whereas 60% RFB needed 15% oxidized cornstarch or a combination of low levels of oxidized cornstarch and methylcellulose to impart a comparable binding. Therefore, RFB can be formulated with only oxidized cornstarch at high level or with a low level of starch in combination with methylcellulose. In addition, RFB needs to be formulated with a gum providing high-suspension capacity such as xanthan gum because RFB settles out quickly. This finding is in agreement with the work of Kohlwey (1993), who found that time and temperature had effects on batter viscosity. The viscosity of RFB with 40% solids at 10 C decreased greatly after 10 min compared with that of WFB with 35% solids. Hsia et al. (1992) also found that batters containing xanthan gum showed the highest apparent viscosity compared with guar gum, carboxymethylcellulose, and control batters.

In conclusion, with appropriate levels of oxidized starch, methylcellulose, and xanthan gum, the adhesion property of RFB improved. Microstructural and texture analyses together provided a better understanding of batter adhesion. The LSCM proved to be a powerful tool for imaging the physical properties between batter ingredients and chicken skin. The newly developed attachment for texture analysis is a practical tool for measuring batter adhesion at the interface between the batter and chicken drumsticks. However, further modifications are needed to improve attachment capability, because it works well only for chicken drumsticks ranging in weight from 100 to 130 g.

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