Thermal and Rheological Properties and Textural Attributes of Reduced-Fat Turkey Batters

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ABSTRACT Currently, modified potato and tapioca starches are used as functional additives in formulating reduced- and low-fat frankfurters. However, cornstarches may serve as alternative sources for comminuted meat systems. Meat batters formulated with ground turkey, 2% sodium chloride, 25% distilled-deionized water (ice), and 4% starch, including acid-thinned dent corn (ATDC), cross-linked waxy maize (XLWM), cross-linked dent corn (XLDC), modified potato (MP), acid-thinned dent corn with xanthan gum (ATDCG), or modified tapioca (MT) were compared. Thermal and structural properties of the batters were evaluated using differential scanning calorimetry (DSC) and dynamic rheological testing. Cooking loss, reheating loss, and texture profile analysis (TPA) were determined for cooked turkey batters.

The DSC peak temperatures ranged from 57.5 to 74.9 C, which correlated positively to onset temperatures of the storage moduli ($G'$) for XLWM starch. Incorporation of XLWM, XLDC, MT, or MP starch into turkey batters resulted in significant reductions in cooking and reheating losses.

The TPA results showed that 9.42, 8.57, and 8.48 kg of force were required for 75% compression of cooked batter segments containing MP, XLDC, and XLWM starches, respectively. Segments prepared with ATDCG starch were the least firm and most springy of all starch-containing segments.

(Key words: turkey, starch, thermal properties, rheological properties, textural attributes)


INTRODUCTION United States consumers are requesting quality, reduced-fat frankfurters with the flavor and texture of full-fat frankfurters. Between 1988 and 1991, the number of low- or no-fat foods quadrupled (Anonymous, 1992). In 1993, the introduction of new meat, poultry, and seafood items declined because of higher production costs and lower profit margins (Anonymous, 1993a). Furthermore, sales of several brands of low-fat frankfurters declined in 1993 as compared to sales in 1992 (Anonymous, 1993b).

Yackel and Cox (1992) cited several attributes associated with fat for meat and meat products, including flavor, mouth feel, juiciness, firmness, satiety, handling, emulsion, and heat transfer. Food ingredient manufacturers are faced with the challenge of developing mimics that meet the criteria for flavorful, reduced- and low-calorie, meat products. Therefore, choosing a mimic for a particular food application is difficult. Reformulation requires several key elements, including availability, cost, shelf stability, and ingredient familiarity. To satisfy consumers, the food industry has developed an array of low-calorie, starch-based, fat replacers or fat mimics to add to poultry frankfurters. Modified starches from roots, tubers, and cereals are included in this group.

According to Kuhn (1995), regular frankfurters contain an average of 13 to 17 g fat and 150 to 190 cal per frankfurter, whereas a reduced- or low-fat hot dog typically contains 1 to 9 g fat and 50 to 110 cal. Because the demand for reduced- and low-fat frankfurters is increasing, various food ingredients are utilized during processing to bind the additional water that replaces the fat. Currently, the meat industry uses modified starches in low-/no-fat processed meat products such as poultry frankfurters (Keeton, 1996). These starches exhibit a high viscosity, gelation temperature of about 70 C or below, ability to form a semirigid gel, high resistance to shear, and low hydration temperature (Luallen, 1985, 1988).
Research is needed to further evaluate the functionality of modified starches in reduced-fat poultry products. Characterization of selected starch systems will assist processors in selecting appropriate ingredients in meat batter for manufacture of low-fat, poultry frankfurters. The objectives of this research focused on the 1) rheological and thermal properties of modified starches and turkey batters prepared with these starches, 2) cooking and reheating losses of turkey batters associated with thermal processing, and 3) textural attributes of cooked turkey batters.

MATERIALS AND METHODS

Starch Samples

Four different cornstarches, including acid-thinned dent corn (ATDC), cross-linked waxy maize (XLWM), cross-linked dent corn (XLDC), and ATDC with xanthan gum (ATDCG), plus modified tapioca (MT) and modified potato (MP) starches were used. Acid modification and cross-linking of starch were done via hydrolysis (HCl treatment in a slurry or dry state) and cross-linking between hydroxyl groups (phosphorus oxychloride and adipic acid), respectively. The starch slurries were prepared by dispersing 20 g of starch in 100 mL of distilled water. Each slurry was mixed in a beaker for 2 min at room temperature.

Raw Meat

Logs of ground turkey were blended in a Hobart mixer at speed 8 for 5 min. Samples of meat each approximately 700 g, were placed in polyethylene bags; vacuum-packaged using a Hollymatic vacuum packager and stored at 0 C until time of batter preparation.

Chemical Analysis

Ground turkey samples were taken from four random locations within the vacuum package and analyzed for moisture, fat, and protein contents as outlined in AOAC (1990) procedures 950.46, 976.21, and 977.14, respectively. Each test was performed in triplicate.

Preparation of Turkey Meat Batters

Seven different meat batters formulated with ground turkey, 2% NaCl, 25% distilled-deionized water (ice), and 4% starch were compared. Prior to batter preparation, the 700-g meat block was thawed at 4 C for 18 ± 4 h. The temperature of the meat block at the end of thawing was 3 ± 2 C. Ground turkey and NaCl were mixed in a Hobart bowl chopper (1,725 rpm) for 30 s to extract the salt-soluble proteins. This mixture then was blended with approximately 1/3 of the distilled-deionized water (ice) for 30 s, and the bowl was scraped thoroughly. The final phase of the mixing incorporated the starch and the remaining ice into the batter with a blending time of 1 min. The batter temperature did not exceed 12 C during processing. The batter then was scraped from the sides of the bowl, 300-g samples were placed in polyethylene bags, and the bags were vacuum-packaged (28 mm Hg). Vacuum-packaged samples were placed in a 4 C environment until further testing.

Thermal Analysis

Differential scanning calorimetry (DSC) was performed on starch slurries and turkey batters. Before samples were analyzed, the instrument was calibrated using an indium standard. Twenty percent starch slurries ranging in weight from 9.2 to 14.3 mg were sealed in aluminum sample pans with lids (Perkin-Elmer kit no. 0219-0062). Weighed samples were evaluated using a Perkin-Elmer DSC 4.9 Hermetically sealed pans containing pieces of aluminum and having similar weights served as references. The scanning temperature range was 30 to 115 C with a heating rate of 10 C/min. An instrument sensitivity of 0.2 mcal/s was selected. Onset gelatinization temperature (Tg), peak temperature (Tp), and enthalpy (ΔH) were calculated for the starch slurries. Gelatinization temperature range was defined as the onset temperature to the final temperature. Data acquisition, retention, and examination system (DARES) software for DSC version 2.0E10 was used in all determinations and ΔH calculations.

Dynamic Rheological Testing

Thermorheological properties of starch samples and turkey batters containing starch were assessed by small amplitude dynamic oscillatory tests using a Bohlin VOR rheometer. Samples were placed in a 1.0-mm gap between two stainless steel parallel plates with a diameter of 30 mm. The sample perimeter was covered with a thin layer of high-temperature-resistant silicone grease to prevent sample dehydration. To further minimize heat loss, the unit was enclosed in an insulated shell. Strain sweep was used to determine the region in which the storage modulus (G’) is independent of strain. Dynamic oscillatory measurements were monitored at a frequency of 1.0 Hz and strain of 2.66%. After initial equilibration at 20 C for 5 min, the sample was heated continuously at a rate of 1 C/min from 25 to 90 C.

Cooking and Reheating Losses

Cooking and reheating losses were determined using a modified procedure described by Payne (1993). Each
turkey batter was packed into nine, 50 mL, polypropylene centrifuge tubes\textsuperscript{13} (30 mm diameter). Thermocouples were inserted through the caps to the geometric center, and the internal temperature was monitored using a Doric 205 thermometer.\textsuperscript{14} Tubes were heated in an 85 °C water bath until an end point temperature of 78 ± 2 °C was attained, then the tubes of batter were placed in an ice water bath to prevent further cooking. Cooked batters were removed from the tubes using a metal spatula. Immediately after removal, the samples were blotted dry and weighed. Cooking losses were determined on batters immediately after removal, allowed to stand for 6 min. Reheated segments were cooled for 2 min, and weighed. Reheating losses were calculated as follows: 

\[
\text{Reheating loss} = \frac{\text{initial weight} - \text{reheated weight}}{\text{initial weight}} \times 100
\]

Three segments measuring 70 ± 5 mm in length and 29 ± 1 mm in diameter were obtained from the cooked batters and used to determine reheating losses for each treatment. Each sample of cooked batter was placed in a beaker containing approximately 300 mL of boiling, distilled water. Beakers were covered with watch glasses and allowed to stand for 6 min. Reheated segments were drained on a paper towel, cooled for 2 min, and weighed. Reheating losses were calculated as follows: 

\[
\text{Reheating loss} = \frac{\text{initial weight} - \text{reheated weight}}{\text{initial weight}} \times 100
\]

**Texture Profile Analysis**

Segments measuring 20 mm were taken from the middle of the cooked turkey batters and used for texture profile analysis (TPA). Segments were compressed to 75% of original height (15/20 mm) using the TA.XT2 Texture Analyser.\textsuperscript{16} Prior to testing, force and probe height were calibrated. A 25-kg load cell with an instrumental test and post-test speed of 8 mm/s and a time interval of 1 s between compression bites was used in order to simulate human chewing action. Texture Analyser PC software package XT.RA dimension\textsuperscript{16} was used to determine hardness (force value corresponding to the first major peak), fracturability (force value corresponding to the fracture point), adhesiveness (negative area or force), cohesiveness (the ratio of the area of the second penetration/area of the first penetration), springiness (physical recovery after the product has been deformed), gumminess (hardness × cohesiveness), and chewiness (gumminess × springiness). Parameters for TPA setup and method setting were established based on preliminary work.

**Statistical Analysis**

Data were subjected to ANOVA using a randomized block design, with starch types representing the treatments and time serving as the blocking factor. Three replications were performed, with each replication representing a block. Six subsamples were averaged for TPA and cooking loss, whereas three, two, and two subsamples were averaged for reheating loss, rheology, and thermal analysis, respectively. Mean comparisons were made when the main effects were significant (\(P < 0.05\)).

### RESULTS AND DISCUSSION

#### Chemical Analyses

Mean protein, fat, and moisture values for the ground turkey meat were 18.5 ± 0.08, 10.8 ± 0.4, and 72.0 ± 0.9%, respectively.

#### Thermal Analysis

**Starch Samples.** Endothermic onset temperatures (\(T_o\)) for the starches ranged from 49.9 to 67.6 °C (Table 1).
cereal starches had a narrower temperature range than MP and MT. The $T_o$ values for MP and MT starches were significantly lower than those for the cereal starches. The broader temperature range and lower temperature of the endotherms of the MP and MT starches indicates that the starch granules might have been damaged during the modification process. Stevens and Elton (1971) found that the starch source (plant, root, or tuber) was responsible for differences in $T_o$ and $T_p$ values and $\Delta H$ values (Wootton and Bamunuarachchi, 1979a,b). The modification procedure and heating rate also play a role in endothermic temperatures.

The $T_o$ value of XLWM starch was significantly greater than that of XLDC starch. The XLWM starch has a higher proportion of amylopectin, which is responsible for more branching compared to the nonwaxy starches. Furthermore, the process of cross-linking increases the gelatinization temperature for the XLWM starch. Wada et al. (1979) concluded that differential thermal analysis curves in the region of $T_o$ reflected structural changes of the starches in the initial gelatinization stage, and those in the region above $T_p$ reflected changes that correspond to an increase in viscosity.

The ATDC starch had the highest $T_o$ of all the starches, presumably because the amorphous chains cannot assist in the melting of the crystalline areas. The ATDCG starch did not exhibit a defined endothermic peak; however, a slight aberration was noted in several thermograms at 80.5°C. This aberration might have been due to the xanthan gum competing with the starch granules for the water. Close examination of the ATDCG starch thermogram showed that the $G'$ onset temperature was close to the ATDC endothermic peak.

The $\Delta H$ values for MP and ATDC starches were at least 32% higher than those for XLDC, MT, or XLWM starches (Table 1). Stevens and Elton (1971) found that the $\Delta H$ values for potato starch were 36% higher than those for maize starch, which corresponds to our results. The $\Delta H$ values for MP starch were 37.8% higher than those for XLWM starch. The $\Delta H$ value found for MP starch was considerably lower than that reported by Kuntzel and Doehner (1939); however, those workers used a stirred dilute solution.

**Turkey Meat Batters.** Three distinct endothermic peak temperatures for raw, ground, turkey meat occurred at 60, 68.5, and 76.5°C. Similar findings were reported for thigh muscle, which exhibited three major transitions at 60, 66, and 76°C (Kijowski and Mast, 1988). Thermal curves of isolated protein fractions indicated that the thermal transitions in muscle corresponded to the denaturation temperatures of myosin, sarcoplasmic proteins, and f-actin.

Endothermic peaks at 60, 66, 73, and 80°C were seen in turkey batters prepared with ATDC starch. The fourth peak temperature of 80°C corresponded to the final temperature in the DSC thermogram for that starch. One disadvantage of using ATDC starch in processed meat products is the requirement of a higher processing temperature in order to initiate starch gelatinization.

Thermograms of turkey batters prepared with the other starches showed only three endothermic peaks at 62, 67, and 74°C. Starch gelatinization, protein denaturation, and melting of fat are separate events that occur in the batter system and are difficult to differentiate. No significant differences in onset, peak, or final temperatures were found among batters.

**Dynamic Rheological Testing**

**Starch Samples.** The onset $G'$ temperature of MP and MT starches did not differ (Table 1). The $G'$ onset temperature is indicative of structure development that may suggest the interaction of the starch components, amylose and amylopectin. The $G'$ onset temperature is reflective of the $T_o$ data for MP and MT. Amylose and amylopectin might have been more available for interacting, which leads to an earlier demonstration of elastic properties compared to the other starches.

The XLDC starch had a significantly lower onset $G'$ temperature than XLWM starch. This might be because XLDC starch had a higher amylose:amylopectin ratio. Amylopectin is a more heat-stable molecule and does not gelatinize as fast (Luallen, 1985). The slower rate of gelatinization would lead to earlier development of elastic properties for XLDC starch than for the XLWM starch.

The onset $G'$ temperatures for XLWM and ATDC starches were significantly higher than those for the other starches. High levels of cross-linking increase the starch's gelatinization temperature and, therefore, the $G'$ onset temperature.

The ATDCG starch did not show an onset $G'$ temperature. This result might have been due to the xanthan gum inhibiting structure formation and interrupting gel formation. Eliasson (1986) characterized the viscoelastic behavior of wheat, maize, potato, and waxy-barley starches during gelatinization and found an initial peak for all starches, followed by a second peak at 90 to 95°C in the wheat and maize starches. Because starch suspensions used in our experimentation were not heated to 95°C and maintained at that temperature for 10 min, the second peak may have been suppressed.

According to Eliasson and Bohlin (1982), the starch gel is a composite material of granules in a polysaccharide matrix. Various properties of starch, such as concentration, granule size and shape, and granule-amylose/amylopectin interactions, are cited as factors that can influence the rheological behavior of starch gel (Eliasson, 1986). In order to fully understand the rheological changes during gelatinization of starch, such factors should be evaluated.

**Turkey Meat Batters.** The MP starch exhibited a significantly lower onset $G'$ temperature than the other starches, which corresponds to the DSC endothermic data. The onset endothermic peak temperature of 51.1°C suggested that starch gelatinization started well below denaturation of the ground turkey meat proteins (60°C). The larger size of the potato starch granule compared to
the other starches (Hoseney, 1994) might have caused earlier hydration and gelatinization compared to the other starches. By reducing the available water and impeding free water from flowing, hydration allowed earlier structure development than with the other smaller and modified starches.

The other batters exhibited structure development at approximately 61°C, which is the temperature at which the first turkey protein T_p was measured. Therefore, the combination of muscle protein and starch hydration and partial gelatinization might have been responsible for the structure development. The ATDC starch had an endothermic onset temperature of 67.6°C. According to Hoseney (1994), the ATDC starch chains remaining after acid treatment are smaller and tend to associate with each other more easily. Together with the muscle proteins, the partially hydrated ATDC granules that have associated other more easily. Together with the muscle proteins, the partially hydrated ATDC granules that have associated other more easily.

Changes in starch structure such as melting or gelatinization are affected by rate of heating, temperature, amylose:amylopectin ratio, shear, granule size distribution, proteins, lipids, and salts (Donovan, 1977, 1979; Eliasson, 1986; Lai and Kokini, 1991; Kokini et al., 1992). These factors also affect the resulting viscoelastic properties of starch. Furthermore, rheological changes during processing determine the textural properties of the finished product and can be used to predict muscle functionality of comminuted meat products such as frankfurters (Hamann, 1988).

### Cooking and Reheating Losses

Cooking losses of turkey batters were affected significantly by the addition of the selected starches (Table 2). A cooking loss of 8.41% was seen in the batter prepared without starch, whereas batters containing XLDC, MP, MT, and XLWM starches had cooking losses of 1.70, 1.61, 1.50, and 1.18%, respectively. Skrede (1989) reported that sausages containing MP starch and cooked to a core temperature of 80°C had a cooking loss of 1.5%, whereas a cooking loss of 0.8% was reported for sausages containing MT.

Although ATDC and ATDCG starches reduced cooking losses in batters, these starches were not as effective as MP, MT, XLWM, or XLDC because of the starch modification process. Furthermore, cooking loss differences were seen because certain starches improved water binding capacity and reduced cooking losses. No significant difference in pH was noted among the seven treatments, which is indicative that pH did not play a role in reducing cooking losses.

Similar results were seen when comparing reheating losses of cooked turkey batters prepared with or without starch (Table 2). Addition of XLWM, MP, XLDC, or MT starch decreased reheating losses by 57, 56, 54, and 54%, respectively.

### Texture Profile Analysis

Incorporation of selected starches into the turkey batter system significantly influenced most textural attributes (Table 3). However, no significant difference in spring-
ness was noted among treatments. Although no fracture peaks were detected, average hardness (firmness) values for segments containing MP, XLDC, and XLWM starches were 9.42, 8.57, and 8.48 kg, respectively. Hand et al. (1987) found that low-fat frankfurters required 1.3 times as much force to shear than frankfurters containing a higher fat level. No significant differences were noted for any textural attributes of segments containing MP, XLWM, and XLDC starches, which indicates that the cross-linked cornstarches share similar properties with MP starch and possibly could be used in meat batter systems without significantly altering textural properties.

Claus and Hunt (1991) used wheat starch to improve the texture of low-fat, high-added-water bologna and found that the result was a firmer, more cohesive product. Comer et al. (1986) used an XLWM starch in 22 to 26% wiener formulations and concluded that textural firmness increased with the addition of 10.3% starch in comparison to all-meat controls.

Segments containing ATDCG starch and segments with no starch added were significantly less hard than all other samples. In addition, ATDCG starch significantly decreased cohesiveness in cooked segments. When the ATDCG-sections had cohesiveness values that were 30, 48, and 51% lower, respectively, than segments that contained no starch, MP, or XLDC cohesiveness values that were 30, 48, and 51% lower, respectively.

**Conclusion**

The modified starches varied in their ability to improve firmness and other textural characteristics of reduced-fat, high-added water, turkey batters. In a water-added system such as that used for reduced-calorie poultry products, cross-linked starches serve to reduce cooking and reheating losses and provide textural attributes similar to those found in processed meats containing MP or MT. In addition, thermal properties of cross-linked starches enable the food processor to use a lower processing temperature, which results in higher smokehouse yields and improved quality of products.

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