Reduced-Fat Bologna Manufactured with Poultry Skin Connective Tissue Gel

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ABSTRACT The objectives of this study were to determine temperature (50, 60, 70, and 80 °C) and time (0.5, 1.0, 1.5, and 2.0 h) effects on the water binding ability of chicken skin connective tissue (CCT) and its ability to form model gels; to develop and determine the functionality of added water (AW, 100, 200, and 300%) CCT gels; and to evaluate the attributes of reduced-fat bologna containing 10 to 30% addition of 100 to 300% AW CCT gels. Heating (60 °C) CCT for 0.5 h allowed the formation of model CCT gels containing 100 to 300% AW. Added water decreased CCT gel fat, protein, collagen content, and hardness due to a protein (collagen) dilution. Hydration values were sufficient to allow CCT to bind up to 300% AW. Gel fragility and syneresis were observed in higher AW CCT gels due to protein dilution, a result of the high fat content of raw CCT (~40%) and added water. Percentage gel addition and AW decreased (P < 0.05) the hardness of reduced-fat CCT gel bologna. All bologna treatments exhibited acceptable sensory attributes. This study indicated the feasibility of using lower AW CCT gels as texture-modifying agents in reduced-fat comminuted meat products.

(Key words: connective tissue, reduced-fat, collagen, chicken skin, gels)

INTRODUCTION

Chicken skin connective tissue (CCT), a by-product of fabrication operations, could be a potential water binder and texture-modifying agent for use in reduced-fat comminuted meat products. Improving the functionality (solubility) of CCT may increase its potential use in comminuted meat products as a less expensive water binder or texture-modifying agent.

The functionality (water binding) of CCT could be improved prior to thermal processing or during thermal processing. Mechanical modification (Eilert et al., 1993; Graves et al., 1993; Blackmer et al., 1994; Delmore and Mandigo, 1994), phosphates (Ranganayaki et al., 1982; Eilert et al., 1994), solvents (Kenney et al., 1986), heating (Sadler and Young, 1993), or a combination of factors such as pH, salt, phosphates, and water (Puolanne and Ruusunen, 1981) have been employed to improve collagen solubility. Bonifer et al. (1996) utilized a sodium bicarbonate washing process to remove fat from chicken skin to concentrate the protein content prior to incorporation in bologna.

Preheating CCT to a gelatinous state converts collagen to gelatin, a strong water binder (Satterlee and Zachariah, 1973). Conversion of CCT collagen to gelatin by heating, with subsequent addition of water, could form a gel which, if incorporated into reduced-fat meat products, may improve product yield, texture, and palatability. The objectives of this study were to determine temperature (50, 60, 70, and 80 °C) and time (0.5, 1.0, 1.5, and 2.0 h) effects on the water binding ability of CCT and its ability to form model gels; to develop and determine the functionality of added water (AW, 100, 200, and 300%) CCT gels; and to evaluate the attributes of reduced-fat bologna containing 10 to 30% addition of 100 to 300% AW CCT gels.

Abbreviation Key: AW = added water; CCT = chicken skin connective tissue.

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MATERIALS AND METHODS

Connective Tissue Modification

The CCT was removed from the breast muscles of 6- to 8-wk-old broilers obtained from a local poultry processor. The CCT was layered on plastic-lined stainless steel trays, covered with plastic, and placed in a −4°C freezer for approximately 4 h until the outer surface of the CCT was frozen (crust-frozen). Crust-frozen CCT was ground through a coarse (1.27 cm) plate, relayered (3 to 5 viewable layers), and frozen at −22°C for 24 h. The frozen, coarse ground CCT was chopped for 1 min in a table top bowl chopper with a blade speed of 3,650 rpm and bowl speed of 20 rpm, producing chips approximately 1.5 mm in diameter. Approximately 1.8 kg of the free-flowing connective tissues were double bagged in polyethylene plastic bags and stored at −32°C until analyzed or used for gel manufacture.

Experiment 1

Proximate Composition, Collagen Content, and Released Fluids. The CCT was analyzed for proximate composition according to AOAC methods (1990; 950.46B, 991.36 and 981.10, respectively). Total collagen content (milligrams per gram; Hill, 1966) was determined by calculating hydroxyproline content (Bergman and Loxley, 1963; Kolar, 1990). A conversion factor of 7.25 was used (Goll et al., 1963) to express total collagen on a milligram/gram basis. Triplicate raw CCT samples (17 g ± 0.05) were weighed in 50-cc polycarbonate tubes and heated in a water bath at a single temperature (50, 60, 70, or 80°C) for a specific time (0.5, 1.0, 1.5, or 2.0 h). Fluids released from heated CCT were collected in 15-mL graduated cylinders, which were centrifuged for 10 min at 4,378 × g (25°C). Centrifugation separated the fluids into layers of fat, gel-water [a mixture of solubilized CCT collagen (gelatin) and moisture (free water) contained in the CCT], and proteinaceous solids (insoluble chicken skin particles) components, which were measured by the graduated scale in 15-mL cylinders. Total fluids (fat, gel-water, and solids), fat, gel-water, and proteinaceous solids were reported as milliliters released per 100 g of CCT (Townsend et al., 1968).

Water Binding (Hydration). Appropriate amounts of CCT and distilled, deionized water were combined in 50-cc polycarbonate centrifuge tubes and heated in a water bath at a single temperature (50, 60, 70, or 80°C) for 0.5 h to create 25 ± 0.01 g gels containing 100, 200, or 300% AW on a wt/wt basis (CCT:AW). The tubes were then removed from the water bath, covered with paraffilm, and stored (2°C) for 14 to 16 h. The tubes of CCT gel (2°C) were centrifuged 15 min at 32,566 × g. Released fluid was decanted through a single layer of cheesecloth into preweighed tubes and hydration determined as grams of water held per gram of connective tissue.

Statistical Analysis. The experiment was designed as a split plot with a factorial arrangement of treatments. Water bath temperature was the whole plot factor and time, for the determination of released fluids or AW, for hydration determination, the split plot factor. The model included the main effects of temperature and time or AW and all two-way interactions. Replication by temperature was the whole plot error term, with residual error used for the split plot factor and interactions. Main effects and interactions were tested for significance (P < 0.05) using the General Linear Models (GLM) procedure of SAS® (1991a). Significant main effect means were separated using Fisher’s least significant difference (Lentner and Bishop, 1986). Orthogonal contrasts (Steel and Torrie, 1980) were used to determine main effect and interaction trends. The experiment was replicated twice (n = 32, for released fluids; n = 24, for hydration).

Experiment 2

Connective Tissue Gel Formation. Prescribed amounts of connective tissue and distilled water were combined in 600 mL beakers to produce ~500 g gels containing 100, 200, or 300% AW (wt/wt, CCT:AW). For example, 250 g CCT + 250 g AW = 500 g of 100% AW CCT gel. Gels were formed by heating the CCT and water at 60°C for 30 min in a water bath in the same manner as described in Experiment 1. It was observed during preliminary gel formation testing that separate layers of CCT, gelatin/water, and fat were formed within the gels. In order to ensure a uniform mixture of CCT, gelatin, water, and fat components within a particular CCT gel treatment, the gels were removed, placed on stirring plates, and mixed at high speed, with stir bars in a cooler (2°C), to disperse CCT particles, gelatin, water, and fat to create a uniformly suspended CCT gel matrix. The stir bars were removed when the gels thickened, and the gels were covered with parafilm and refrigerated (2°C) until analyzed (14 to 16 h).

Proximate Composition, Collagen Content, and pH. All CCT gels were analyzed in duplicate for proximate composition (AOAC, 1990) and total collagen content, as described previously. Soluble collagen was determined according to the procedure of Eilert and Mandigo (1993). Duplicate gel sample pH readings were taken with a spear-tip electrode® (Model 8163BN) attached to a pH meter® (Model SA720).

Hydration and Cook Stability. Hydration, a measure of water binding, was conducted on duplicate 25 g (± 0.05 g) CCT gels as described previously, and expressed as

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grams of water held per gram of connective tissue. Cooking stability, an indicator of the ability of the CCT gels to retain water after heating, was determined by the method of Townsend et al. (1968). Gel samples (25 ± 0.05 g) were weighed into 50 cc polycarbonate centrifuge tubes and the tubes placed in a 48.8 C water bath. The temperature of the water bath was gradually raised until the internal temperature of the samples reached 68.8 C within 1.25 to 1.50 h. The free liquid was decanted and cooking stability expressed on a sample percentage basis.

**Color, Kramer Shear, and Texture Profile Analysis.** Sample gel discs (22 mm diameter × 12 mm height) were used for HunterLab color and texture profile analyses. Tripletake sample gel discs were used for HunterLab Colorimeter5 analysis (Illuminant A, 2° standard observer). One reading was taken on each surface of the sample discs for HunterLab L* (lightness), a* (redness), and b* (yellowness) values. Triplicate gel disc samples were used for two-cycle compression testing using an Instron Universal Testing Machine5 (Model 1123) and compressing each gel sample twice to 25% of average sample height (75% compression, from 12 to 3 mm at 2 C). A 500-kg load cell was used with a full scale load range of 0 to 1.0 kg, crosshead speed of 100 mm/min and a chart ratio of 5:1. The textural parameters of hardness, cohesiveness, springiness, and chewiness (Bourne, 1978) were determined per gram of gel.

**Statistical Analysis.** Experiment 2 was analyzed as a randomized complete block with a single factorial (AW) treatment design. Fisher’s least significant difference (Lentner and Bishop, 1986) was used to separate significant (P < 0.05) main effects. Orthogonal contrasts were used to determine main effect trends (Steel and Torrie, 1980). Pearson correlation coefficients were determined for variables of interest (SAS Institute, 1991a). The experiment was replicated three times (n = 9).

**Experiment 3**

**Bologna Manufacture.** Nine bologna treatments (Table 3) were formulated based on a 2 × 2 central composite design (Cochran and Cox, 1957). The AW in CCT gels ranged from 100 to 300% with the percent gel incorporated ranging from 10 to 30%. The prescribed amounts of CCT and water were placed in a preheated (60 C) steam jacketed kettle7 (Groen TDC/2) for 0.5 h, then removed from the kettle and mixed8 (Model K5SS) for 0.5 h at setting 3 in a 2 C cooler. The gels were placed in plastic containers, covered, and stored at 2 C for 16 h prior to bologna manufacture.

Frozen raw materials (90% lean/10% fat beef trimmings) obtained from the rounds of commercial steer carcasses were tempered at 4 C for 3 d prior to manufacture. The material was coarse ground3 (Model 4732) through a 1.27 cm plate, thoroughly mixed, and analyzed for proximate composition and collagen content. Lean meat (4.54 kg), salt (158 g), and 3% AW were combined in a table top bowl chopper9 (Model 8181D), with a blade speed of 3,625 rpm and a bowl speed of 20 rpm. The mixture was chopped for 1 min, then the appropriate percentage of cubed (25 × 25 mm) CCT gel was placed in the bowl chopper and chopped 1 additional min. The remaining lean meat, commercial seasonings (2% basis on finished weight basis), sodium nitrite (156 ppm, meat block basis), and sodium erythorbate (350 ppm, meat block basis) were added and chopped one additional min for a total of 3 min chopping time. The meat blend was then removed from the bowl chopper and passed once through an emulsifier9 (Model MCV 12) and stuffed with a piston-type water stuffer9 into prestuck, 60 mm fibrous casings.

Bologna were thermally processed in an Alkar single truck smokehouse10 to an internal temperature of 65 C using a standard smokehouse cycle. The bologna was stored (2 C) for 18 h, sliced into 0.5-kg chubs, and vacuum packaged in pouches (20.3 × 45.7 cm). The cured, fully cooked, vacuum-packaged bologna was stored at 2 C until analyzed.

**Proximate Composition, Collagen Content, pH, Purge, and Expressible Moisture.** Proximate composition, collagen content, and pH of raw and cooked bologna batters were determined as described previously (Experiment 2). Four cooked bologna chubs (0.5 kg each) were selected for purge and two for expressible moisture (Jauregui et al., 1981) after 21 d of storage (2 C) and expressed on a percentage basis.

**Cook Yields, Cook Stability, and Back Extrusion.** Each bologna treatment was weighed after stuffing, after thermal processing, and after an 18 h chilling period to calculate percentage cook and chill yields. Three 50-cc polycarbonate centrifuge tubes were stuffed with 25 ± 0.05 g of raw bologna batter and the tubes placed in a 48.8 C water bath. The temperature of the water bath was gradually raised until the internal temperature of the samples reached 68.8 C within 1.25 to 1.50 h. The free liquid was decanted and cook stability expressed on a percentage basis (Townsend et al., 1968).

Duplicate 300-g samples of raw bologna batter was utilized for back extrusion (Bourne and Moyer, 1968) using an Instron Universal Testing Machine5 (Model 1123) with a stainless steel cylinder (10.1 cm internal diameter) and a plunger (9.3 cm in diameter), providing a 4-mm annulus. The plunger was stopped 3 mm from the bottom of the cell. A 500-kg load cell was used with a 0 to 50 kg full scale load, crosshead speed of 100 mm/min, chart speed ratio of 2:1 and a return limit of 90 mm. Peak force (Newtons) and total energy (Joules) to extrude the samples were calculated on a per gram sample basis.

**Color, Kramer Shear, and Texture Profile Analysis.** Three sample slices (60 mm diameter × 12 mm thick) of
cooked bologna were used to determine cured meat color intensity using a 650 nm/570 nm reflectance ratio (Erdman and Watts, 1957). Readings were taken at 21 d of storage (2 C).

The Universal Instron Testing Machine\(^5\) (Model 1123) with a Kramer-Shear attachment determined the peak force (Newtons per gram) and energy (Joules per gram) required to shear cooked bologna slices (60 mm diameter \(\times\) 3 mm thick) at 8 C. Crosshead speed was 100 mm/min with a proportional chart speed of 2:1. Three sample slices (60 mm diameter \(\times\) 12 mm thick) were used for two-cycle compression testing to determine hardness, cohesiveness, springiness, and chewiness under the conditions described previously except that a full scale load of 0 to 1 kg was used.

**Sensory Evaluation.** After 3 wk of storage (2 C), a consumer sensory panel determined the attributes of juiciness, texture, flavor and overall acceptability (IFT Sensory Evaluation Division, 1995) of CCT bologna. Bologna slices (60 mm diameter \(\times\) 3 mm thick) were cut into wedge-shaped quarters weighing approximately 2 g each. Two samples per treatment combination were served cold (8 C) to panelists on styrofoam plates. Panelists (n > 40 per session) consisting of Animal Science Department graduate students, faculty, and staff evaluated four to five bologna samples per session (one session per day, 3 d total). Data were collected on sensory evaluation ballots using an eight-point scale (1 = Extremely undesirable and 8 = extremely desirable). The testing location consisted of a room measuring 5 m wide \(\times\) 15 m in length with 10 partitioned booths maintained at 25 C with a relative humidity of approximately 60%. Standardized red fluorescent lighting was used. Each panelist received four to five randomly selected wedges coded with a three-digit number. Room temperature distilled water was provided to cleanse the palate between samples. Expectorant cups were available to panelists to minimize fatigue. All panelist scores for each attribute of each bologna treatment were averaged per replication.

**Statistical Analysis.** A 2 \(\times\) 2 central composite design (Cochran and Cox, 1957) response surface regression (SAS Institute, 1991a) was used for simultaneous analysis of percent added water (factor levels ranging from 100 to 300%) and percent addition of gels (factor levels ranging from 10 to 30%) made with CCT. Nine combinations (Table 3) of the two factors were chosen with one treatment combination replicated four times to derive error degrees of freedom to test for significance. A second-order polynomial equation was fitted:

\[
Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i<j} b_{ij} x_i x_j
\]

where Y was the estimated response; \(b_0\) (constant), \(b_i\) (linear), \(b_{ii}\) (quadratic), \(b_{ij}\) (interaction) = parameter estimates; and \(x_i\) and \(x_j\) = the factor levels; and \(k = \) the number of factors (2). Total response surface regression equations were determined to be significant at \(P < 0.05\).

Regression equations containing significant parameter estimates were used to generate response surface curves using PROC G3D (SAS Institute, 1991b). This experimental design methodology was used to determine significant \((P < 0.05)\) regression equations that could be graphically represented as three dimensional response surfaces. These graphs were used to determine the relationships between the factors of added water and percent gel incorporation; to describe how these factors affect a particular response; and to describe the overall, or combined effect of both factors on a particular response variable. Least squares means were reported in tabular format for all response variables studied for informational purposes, regardless of significance.

**RESULTS AND DISCUSSION**

**Experiment 1**

**Released Fluids and Hydration.** Proximate composition of CCT was 49.57% moisture, 41.32% fat, 9.22% protein, and 18.02 mg/g total collagen. The pH was determined to be 6.25 (data not shown). Temperature increased \((P < 0.001)\) the amount of fat released among CCT samples (Table 1). Similar released fat values (5.17 vs 5.13 mL/100 g CCT) were recorded for 70 and 80 C, respectively, whereas 50 C released less fat than 60 C (3.58 vs 4.38 mL/100 g CCT, respectively).

A temperature by time interaction \((P < 0.01)\) was observed for CCT total released fluids and released gel-water (Table 1). Values ranged from 4.02 to 7.15 mL of total fluids and 0.55 to 1.97 mL of gel-water per 100 g CCT. Less fluid was released from CCT heated at 50 and 60 C than at 70 and 80 C time periods (Table 1). Volumes of released fluid were similar at 60, 70, and 80 C for all time periods.

Gel-water losses were less for CCT heated to 50 C than at 60 C at 0.5 to 1.0 h. Heating CCT to 50 C for 1.5 h exceeded the amount of gel-water released by CCT at 60 C for the same time period (1.56 vs 1.27 mL/g CCT, respectively). The amount of released gel-water was higher at 70 and 80 C than at the lower two temperatures across all times, due to solubilization of chicken skin collagen. In order to produce gels with the ability to bind AW, collagen must be solubilized (gelatin). The ability of CCT to solubilize and form gelatin as a released fluid component after heating suggests the potential for developing an AW CCT gel.

Heating CCT to 60 C may be more advantageous than heating at higher temperatures due to less released fat, which could reduce the effectiveness of CCT in forming an AW gel. Heating CCT to 60 C releases more fat at 0.5 and 1.0 h than heated at 50 C, but has a greater percentage of its total released fluid in the form of gel-water. Upon cooling, the gel-water may have entrapped more of the fat released during heating. This offers greater potential in binding AW and stability of gel formation. There appears to be a trade off between solubilization of collagen and the
melting of fat. Heating CCT to 70 or 80 C temperatures released more gel-water than the lower temperature ranges, but the concurrent increase in released fat may offset the expected advantage of increased water binding (more gel-water), due to preferential binding of the melted fat (hydrophobic interaction) to solubilized collagen, rather than to water (hydrophilic interaction). This interaction is expected, as collagen is approximately 60% hydrophobic (Bailey and Light, 1989), and when heated, the solubilized collagen (gelatin) will be soluble in fat. This solubilization may be an important factor for enhancing the binding ability of connective tissues with higher fat contents.

**Water Binding (Hydration).** Temperature affected \((P < 0.05)\) the hydration of CCT expressed on a connective tissue basis (Table 1). Hydration values for CCT ranged from 0 to 0.08 g water held/g connective tissue. At temperatures above 50 C AW test tube gels containing 100, 200, or 300% AW were formed. At 50 C, CCT did not bind any measurable AW. Heating CCT at 60 C resulted in hydration values similar to CCT heated at 70 C and 80 C. However, heating CCT to 70 or 80 C may be detrimental due to an increase in released fat from CCT when heated to higher temperatures. The fat content, rather than the collagen content of chicken skin, was reported by Froning et al. (1973) to have a greater effect on its functional properties. Removing all or a large percentage of the fat from CCT should enhance its overall water binding ability. Heating CCT to 60 C released less fat, and possessed a similar hydration value compared to heating at 70 or 80 C. This observation suggests that CCT gel formation may be enhanced by heating CCT to 60 C, or by reducing its fat content.

### Experiment 2

**Proximate Composition.** The proximate composition of CCT gels are found in Table 2. As the amount of AW increased, moisture content increased, and fat and protein content decreased. All water added to the CCT was absorbed during gel formation. The CCT gels with 200 and 300% AW contained the greatest percentage moisture (79.79 and 84.84%, respectively), but were extremely fragile and exhibited syneresis at room temperature (25 C). The 100% AW CCT gel contained the most fat (21.23%). Calculated percent moisture of each CCT gel treatment were projected to be approximately 75, 83, and 88% for 100, 200 and 300% AW CCT gels (wt/wt; CCT:AW), respectively. Rather than finding a difference of ~13% in moisture content between the lowest and highest AW CCT gels, a difference of ~9% was found. The missing 3 to 4% moisture may be attributed to either gel syneresis during removal of the gels from the beakers, or to evaporative losses during gel formation.

**Gel pH and Hydration.** The addition of water did not affect the pH of CCT gels. Hydration values increased as AW levels increased, for all connective tissue gel treatments (Table 2). The maximum hydration value (grams of water held per gram of connective tissue protein) was 1.32 for CCT. This value was associated with the ability of CCT to form a gel network. Hydration values greater than 1.04 (CCT) resulted in gels with good water binding, but unacceptable syneresis. Gels with high hydration values (>1.04) may bind additional AW (>200%), but would be expected to exhibit less ability to retain the water during reheating, due to less available collagen for a fibrous gel network to form when cooled.
BOLOGNA MANUFACTURED WITH POULTRY SKIN GEL

TABLE 2. Proximate composition, hydration, pH, cooking stability, melting point temperature, collagen content, color, and objective textural attributes of added water chicken skin (CCT) connective tissue gels

<table>
<thead>
<tr>
<th>Variable</th>
<th>SEM</th>
<th>100%</th>
<th>200%</th>
<th>300%</th>
<th>P Values1</th>
<th>Trends2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture, %</td>
<td>0.21</td>
<td>75.73b</td>
<td>79.79a</td>
<td>84.84a</td>
<td>&lt;0.0001</td>
<td>Linear****</td>
</tr>
<tr>
<td>Fat, %</td>
<td>0.77</td>
<td>21.23a</td>
<td>15.35b</td>
<td>11.50c</td>
<td>&lt;0.01</td>
<td>Linear***</td>
</tr>
<tr>
<td>Protein, %</td>
<td>0.15</td>
<td>4.25a</td>
<td>2.71b</td>
<td>2.35c</td>
<td>&lt;0.01</td>
<td>Linear***</td>
</tr>
<tr>
<td>Hydration, g H2O/g CT3</td>
<td>0.04</td>
<td>0.51c</td>
<td>1.04b</td>
<td>1.32a</td>
<td>&lt;0.01</td>
<td>Linear***</td>
</tr>
<tr>
<td>pH</td>
<td>0.01</td>
<td>6.27</td>
<td>6.23</td>
<td>6.23</td>
<td>&gt;0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Cooking stability, %</td>
<td>0.43</td>
<td>29.82</td>
<td>30.19</td>
<td>29.57</td>
<td>&gt;0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Total collagen</td>
<td>0.53</td>
<td>10.79a</td>
<td>6.96b</td>
<td>4.90b</td>
<td>&lt;0.01</td>
<td>Linear**</td>
</tr>
<tr>
<td>Soluble collagen</td>
<td>0.18</td>
<td>6.29a</td>
<td>3.80b</td>
<td>2.00c</td>
<td>&lt;0.0001</td>
<td>Linear**</td>
</tr>
<tr>
<td>Insoluble collagen</td>
<td>0.62</td>
<td>4.67</td>
<td>3.16</td>
<td>2.89</td>
<td>&gt;0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Percentage soluble collagen</td>
<td>6.24</td>
<td>60.41</td>
<td>55.76</td>
<td>41.45</td>
<td>&gt;0.05</td>
<td>NS</td>
</tr>
</tbody>
</table>

a-cMeans within a row with no common superscript differ significantly.
1Significance levels for main effect of added water.
2Significance levels of main effect (added water) trends.
3CT = connective tissue.
*P < 0.05.
**P < 0.01.
***P < 0.001.
****P < 0.0001.

Collagen Content and Cook Stability. Increasing AW contributed to protein dilution (P < 0.05), reducing the collagen content of each gel, which affected water retention during heating (Table 2). Although soluble collagen content of CCT gels decreased as AW increased, the percentage CCT collagen solubilized among the CCT gel treatments were not affected by AW.

The percentage soluble collagen of CCT ranged from 60.41% (100% AW CCT gel) to 41.45% (300% AW CCT gel). The conversion of CCT collagen to gelatin (45 to 60% soluble collagen) during heating may be attributed to the biomechanical properties associated with connective tissues from the skin (Hukins, 1982). Reduction of CCT fat content prior to formation of AW gels may improve the ability of the gels to bind water through increased protein concentration. Surimi-like processing of chicken skin has been observed to increase protein content (Bonifer et al., 1996).

TABLE 3. Treatment combinations, gel composition, and formulations1 of reduced-fat bologna made with high added water (AW) chicken skin connective tissue (CCT) gels

<table>
<thead>
<tr>
<th>Treatment</th>
<th>AW in gel2</th>
<th>Gel added to bologna3</th>
<th>CCT gel composition</th>
<th>CCT bologna</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CCT Water Fat pH</td>
<td>Added CT4 Gel AW5 Meat6 Proj7 Fat</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>10</td>
<td>0.45 0.45 20.0 6.27</td>
<td>4.95 5.00 8.18 8.45</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>30</td>
<td>1.36 1.36 20.0 6.27</td>
<td>13.86 15.00 6.36 11.65</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>10</td>
<td>0.22 0.68 10.0 6.23</td>
<td>2.42 7.50 8.18 7.31</td>
</tr>
<tr>
<td>4</td>
<td>300</td>
<td>30</td>
<td>0.68 2.04 10.0 6.23</td>
<td>7.48 22.50 6.36 8.22</td>
</tr>
<tr>
<td>5</td>
<td>150</td>
<td>20</td>
<td>0.72 1.09 17.5 6.25</td>
<td>7.92 12.00 7.27 9.48</td>
</tr>
<tr>
<td>6</td>
<td>250</td>
<td>20</td>
<td>0.52 1.30 12.5 6.23</td>
<td>5.72 14.30 7.27 8.34</td>
</tr>
<tr>
<td>7</td>
<td>200</td>
<td>15</td>
<td>0.45 0.91 15.0 6.23</td>
<td>4.95 10.00 7.73 8.40</td>
</tr>
<tr>
<td>8</td>
<td>200</td>
<td>25</td>
<td>0.76 1.51 15.0 6.23</td>
<td>8.36 16.65 6.82 9.42</td>
</tr>
<tr>
<td>g9</td>
<td>200</td>
<td>20</td>
<td>0.60 1.21 15.0 6.23</td>
<td>6.60 13.35 7.27 8.91</td>
</tr>
</tbody>
</table>

1Each batch contained an additional 3% AW to aid in mixing seasonings (2%), sodium nitrite (156 ppm), and sodium erythorbate (550 ppm) on a meat block basis.
2Percentage AW contained in the connective tissue gels.
3Percentage of connective tissue gel added to bologna formulation.
4CT = added connective tissue from gel.
5AW = added water contributed by connective tissue gel treatment.
6Meat composition: Beef trimmings (72% moisture, 8% fat, 19% protein, 13 mg/g total collagen).
8Treatment 9 replicated an additional four times to derive error degrees of freedom to test significance.
Cook stability values of CCT gels were not affected with increasing amounts of AW (Table 3). Cook stability values for CCT gels averaged approximately 30%. The dilution of collagen by AW reduced the ability of higher AW CCT gels to form a solid, fibrous network capable of retaining water during thermal processing. The observed low melting point of the CCT gel upon reheating, suggests a minimal degree of fibril formation and organization.

Correlations were not found between CCT gel cook stability and collagen content. This observation supports the validity of assuming that the high fat content of CCT played a major role in cook stability. Froning et al. (1973) found that fat content rather than collagen content of chicken skin had a greater effect on its functional properties (emulsifying capacity).

**Color and Texture Profile Analysis.** Due to the fragile nature of higher AW CCT gels, only the 100 and 200% CCT gels were analyzed for color and objective texture. Higher AW levels decreased L* (lightness), a* (redness), and b* (yellowness) values for and CCT gels ($P < 0.05$; data not shown). Added water decreased CCT gel hardness values ($P < 0.0001$; data not shown). The 100% AW CCT gel treatment was five times harder (1.22 N/g) than the 200% AW treatment (0.24 N/g). Both CCT gel treatments exhibited well-defined peaks for fracturability (force required to fracture the sample). The 200% AW CCT gel structure was completely destroyed by the first compression stroke, producing no second compression peak, and thus no recorded values for CCT gel cohesiveness, springiness or chewiness (data not shown).

The textural attributes, cooking stability, and observed syneresis of the CCT gels indicate their potential use as a water binding or texture-modifying agent primarily in “cold-serve” rather than “hot-serve” comminuted meat products. However, most comminuted meat products require thermal processing during manufacture. Potential challenges may exist to control yields, texture, and purge loss of comminuted products made with CCT gels.

**Experiment 3**

**Emulsification Temperatures, Processing Yields, and Total Released Liquids.** The nine bologna treatment combinations are shown in Table 3. Table 4 shows the least squares means of processing yields, emulsion temperatures, and released fluids of all bologna treatments. Emulsification temperatures ranged from 10.3 to 18.6 C for CCT gel bologna (Table 4). After thermal processing,
bologna showed no signs of distortion, with minimal gel pockets found on the exterior or interior of the product. Peelability of casing was more difficult for bologna containing gels with higher amounts of AW due to less poor protein film (skin) formation. Cook yields for CCT bologna ranged from 89.91 to 92.08% with an additional 11 to 14% loss after chilling. Total released fluids from CCT bologna ranged from 4.48 to 12.42 mL/100 g (Table 4). Other researchers (Bonifer et al., 1996) found that bologna containing 10 and 20% chicken skin washed in a 0.5% sodium bicarbonate solution, released 11.87 and 11.11 mL/100 g, respectively.

Proximate Composition and Total Collagen Content. The least squares means for proximate composition and total collagen content for each experiment are shown in Table 4. Moisture values for CCT bologna were from 71.32 to 75.42%, with values of 6.12 to 10.50% for fat content and 16.36 to 20.08% for protein content. The CCT bologna total collagen values are shown in Figure 1. Increasing gel addition had little effect on total collagen at the 100% AW, whereas at higher AW levels increasing the addition of gel lowered total collagen content for CCT bologna. Percentage soluble collagen ranged from 14.51 to 35.12% for CCT bologna (data not shown).

Purge, Expressible Moisture, Cook Stability, Cured Color, and pH. The least squares means for the effects of AW and percentage gel addition on CCT bologna purge, expressible moisture, cook stability, and cured color (650 nm/570 nm ratio) are shown in Table 4. Cooked bologna pH values ranged from 5.92 to 5.98 (data not shown). Purge of CCT bologna increased as added gel increased to 20%, then decreased when added at 30%. The addition of gels containing up to 200% AW decreased CCT bologna purge losses, but increased purge was observed from 200 to 300% AW (Figure 1).

The greatest amount of purge for any bologna treatment was 2.54% (300% AW, 30% addition CCT gel bologna). This result indicates that AW CCT gels can retain a significant portion of added water, even after 21 d of storage. Sadowska et al. (1980) reported that the forced

![Figure 1: Response surface curves of significant (P < 0.05) total regression equations for purge, total collagen, and juiciness of reduced fat bologna manufactured with 10 to 30% addition (PERCENT) of 100 to 300% added water (AW) chicken skin connective tissue (CCT) gels.](image-url)
drip of meat homogenates decreased in high collagen meats. Neither AW nor percentage gel addition affected expressible moisture of CCT bologna (31.26 to 42.56%). Cooking stability was from 84.75 to 92.88%.

Collagen may stabilize meat batters during formation, but upon gelatinization of collagen, the protein matrix may be disrupted and, therefore, less stable (Whiting, 1989). Cook losses for bologna batter made with 10 to 20% sodium bicarbonate-washed chicken skin were found to lose 11 to 12% of their weight during thermal processing (Bonifer et al., 1996). The ionic strength, pH, fat level, comminution method, heat processing conditions, and other factors were reported by Jones (1984) to determine the amount of collagen that could be added to a processed meat product.

The cured color of all connective tissue gel bologna treatments in this study ranged from 2.54 to 2.94 (Table 4). A ratio value of 2.2 to 2.6 is considered to be excellent cured color (AMSA, 1991). Response surface regressions found no effect of AW and percentage gel addition on L*, a*, or b* values of CCT bologna. Values ranged from 56.39 to 61.12 (L*), 21.65 to 23.67 (a*), and 13.98 to 15.12 (b*).

![Response surface curves for peak back extrusion values of raw CCT bologna batters and Kramer shear force values of cooked bologna](image)

**FIGURE 2.** Response surface curves of significant \( P < 0.05 \) total regression equations for extrusion peak force, shear force and, hardness vs. reduced-fat bologna manufactured with 10 to 30% addition (PERCENT) of 100 to 300% added water (AW) chicken skin connective tissue (CCT).

**Back Extrusion, Kramer Shear Peak Force, and Texture Profile Analysis.** Response surface curves for peak back extrusion values of raw CCT bologna batters and Kramer shear force values of cooked bologna are found in Figure 2. As gel addition increased, CCT bologna back extrusion and shear peak force values decreased \( (P < 0.05) \). Increasing AW levels slightly increased extrusion peak force and values at 10% gel addition. As AW and gel addition increased, extrusion peak force values decreased.

Table 5 contains least squares means for objective hardness, cohesiveness, springiness and chewiness of CCT bologna. The CCT bologna became softer (Figure 2) as percentage added gel increased across all AW levels. Jones (1984) hypothesized that the inclusion of high collagen meats in low fat formulations may be a means to soften product texture by diluting the stronger binding myofibrillar proteins. Hardness values were reported to decrease for cooked emulsion sausages containing beef tendons that were preheated at temperatures \( \geq 60 \text{C} \) (Sadler and Young, 1993).

**Consumer Taste Panel Scores.** Consumer taste panel least squares means juiciness, texture, flavor and overall
TABLE 5. Least squares means for objective textural and sensory attributes of reduced-fat bologna manufactured with chicken skin connective tissue (CCT) gels

<table>
<thead>
<tr>
<th>TRT</th>
<th>HARD 2</th>
<th>COH 3</th>
<th>SPR 4</th>
<th>CHEW 5</th>
<th>JUICE 6</th>
<th>TEXT 7</th>
<th>FLAV 8</th>
<th>ACCEPT 9</th>
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<tr>
<td>(N/g)</td>
<td>(mm/g)</td>
<td>(J/g)</td>
<td></td>
<td></td>
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</table>

1Consumer taste panel scores based on an 8-point hedonic scale: 1 = extremely undesirable; 8 = extremely desirable.

2HARD = Hardness expressed in Newtons per gram.

3COH = Cohesiveness expressed on a per gram basis (unitless).

4SPR = Springiness expressed as mm per gram.

5CHEW = Chewiness expressed in Joules per gram.

6JUICE = Juiciness.

7TEXT = Texture.

8FLAV = Flavor.

9ACCEPT = Overall product acceptability.

10SEM = Standard error of the mean for treatment combinations 1 to 8.

11SEM = Standard error of the mean for replicated treatment combination.

acceptability are found in Table 5. For CCT bologna, only the factor of percentage gel addition was found to significantly affect any sensory attribute. As gel addition increased, juiciness scores increased across all AW levels (Figure 1). This observation may be a function of variation in total fat content of the CCT bologna treatments (6.12 to 10.50%, Table 4) due to CCT gel fat content (11.50 to 21.23%; Table 2) and the percentage of gel added to the bologna (10 to 30%), rather than the effect of CCT gel addition on final bologna moisture content (71.32 to 75.42%, Table 4). Thermal processing would be expected to cause a decrease in bologna moisture content, concentrating the final fat content of the CCT bologna, which would be expected to affect sensory juiciness and flavor.

Sadler and Young (1993) reported that for any collagen content, sausages containing preheated tendon had a more desirable sensory texture, flavor, and overall acceptability than sausages containing raw tendon. They did note a slight decrease in flavor with increasing collagen content. Bologna containing 10% washed chicken skin rated higher in sensory texture, flavor, and overall acceptability than bologna containing 0 or 20% chicken skin (Bonifet et al., 1996). Bologna made with 10 to 30% addition of gels from CCT had overall acceptability ratings ranging from 4.67 (300% AW, 30% gel addition) to 5.36 (100% AW, 30% gel addition) based on an eight-point scale.

Heating (60 C) CCT for 0.5 h with water allowed the formation of gels containing 100 to 300% AW. Added water decreased CCT gel fat, protein, total and soluble collagen contents, and textural attributes, while increasing hydration values and moisture content. Reheating gels to 68.8 C resulted in poor cooking stability. The incorporation of 10 to 30% CCT gels containing 100 to 300% added water in reduced-fat bologna resulted in finished products with variable processing characteristics and textural and sensory attributes. Bologna containing 30% addition of 100% AW CCT gel was identified as having the most acceptable processing characteristics and textural, and sensory attributes.

Although development of CCT gels is a viable processing technology, consideration should be given to improving gel strength and water binding. Reducing the fat content (~40%) or raw CCT prior to gel manufacture by low temperature rendering should enhance the use of CCT gels as water binders or texture-modifying agents in reduced-fat comminuted meat products.

REFERENCES


