INTRODUCTION

Frankfurters (cooked and cured meat sausages) are one of the most popular convenience food items in the world. Various raw meat materials, seasonings, casing options, and processing techniques provide a myriad of choices for today’s consumers. Currently, the most common processing methods for achieving a homogenous mixture with reduced particle size, commonly called a batter, for frankfurters are coarse grinding using a grinder/mincer, chopping in a bowl chopper (BC), or passing through an emulsion mill (EM). These different methods produce batters of varying meat particle size and technological quality. These different methods were assessed as part of this study to determine their impact on batter stability, processing yield (PY), and texture characteristics and, subsequently, a variety of nonmeat binding ingredients were evaluated for their effects on the products manufactured by the different processing methods.

Effects of processing method and nonmeat binding ingredients on batter stability, yield and texture of frankfurters

Benjamin L. Ruther1 | James S. Dickson1 | Kenneth J. Prusa2 | Rodrigo Tarté1,2 | Joseph G. Sebranek1,2

1Department of Animal Science, Iowa State University, Ames, IA, USA
2Department of Food Science and Human Nutrition, Iowa State University, Ames, IA, USA

Correspondence
Joseph G. Sebranek, Department of Animal Science, Iowa State University, Ames, IA 50011, USA. Email: sebranek@iastate.edu

Funding information
Morrison Endowment at Iowa State University awarded to Joseph G. Sebranek

Abstract

The effects of processing method and added nonmeat ingredients on yield, batter stability, and texture of frankfurters were investigated. Five ingredient treatments (control, sodium alginate (SA), iota carrageenan, transglutaminase (TG), and pork collagen) for frankfurters were produced using three processing methods (coarse grinding, bowl chopper [BC], and emulsion mill [EM]) for each ingredient. Control treatments produced by different methods showed greater (p < .05) processing yield (PY) with the EM, followed by the BC, and coarse grinding, respectively. The addition of TG had a positive impact on textural characteristics of chewiness and cohesiveness, but did not affect PY. As might be expected, differences between frankfurters produced with the different processing methods were observed in this study, and a means to compensate for some of the differences by addition of nonmeat ingredients to the formulations was demonstrated.

Practical applications

This study evaluated the performance of nonmeat binding agents for improving yield and textural quality of sausage products manufactured with three types of comminution equipment. Iota carrageenan and sodium alginate (SA) have potential to improve water retention and yields, depending on the comminution system chosen. Transglutaminase (TG) can be used to modify textural characteristics, particularly in coarsely comminuted products. Combining iota carrageenan or SA with TG showed the greatest potential to compensate for product differences that might be produced by different comminution systems.

1 | INTRODUCTION

Frankfurters (cooked and cured meat sausages) are one of the most popular convenience food items in the world. Various raw meat materials, seasonings, casing options, and processing techniques provide a myriad of choices for today’s consumers. Currently, the most common processing methods for achieving a homogenous mixture with reduced particle size, commonly called a batter, for frankfurters are coarse grinding using a grinder/mincer, chopping in a bowl chopper (BC), or passing through an emulsion mill (EM). These different methods produce batters of varying meat particle size and technological quality. These different methods were assessed as part of this study to determine their impact on batter stability, processing yield (PY), and texture characteristics and, subsequently, a variety of nonmeat binding ingredients were evaluated for their effects on the products manufactured by the different processing methods.

Nonmeat binding ingredients are often used to increase yield and modify sensory characteristics of processed meat products. Sodium alginate (SA) is a nonstarch hydrocolloid that gels in the presence of multivalent ions to form a heat-stable gel (Lamkey, 2009). While
alginate has been investigated for many processed meat applications, there appears to be little published research on the use of SA in emulsion-style products as a means to improve meat batter stability, increase PV, or to modify texture. However, Kang, Wang, Li, Li, and Ma (2020) recently reported that cooking yield and texture were not affected when up to 50% of the fat in frankfurters was replaced by an alginate solution. These authors suggested that alginate could provide a means of reducing the fat content of frankfurters without affecting product quality. Carrageenan (CG) is a linear sulfated polysaccharide derived from several types of red algae species (Ayadi, Kechanou, Makni, & Attia, 2009). The gelling properties of CG and its impact on moisture retention and texture improvements in finely comminuted, processed meat products have been well described (Ayadi et al., 2009; Candogan & Kolsaric, 2003; Yilmaz, Vural, & Yadigari, 2017). There is, however, a lack of agreement on the impact of CG on meat batter stability when used in different processing systems. Transglutaminase (TG) is an enzyme which catalyzes an acyl transfer reaction between amino acid residues of lysine and glutamine (Kuraishi et al., 1997), and provides a cold-binding mechanism that does not require heating to achieve protein cross-linking (Hong & Chin, 2010). The resulting covalent bond creates a new, polymerized protein structure which has potential to improve the textural characteristics of processed meat products, especially those formulated with reduced sodium. Low sodium products typically have less solubilized myofibrillar protein which results in softer texture in finished products. Choi et al. (2017), for example, reported that TG improved the hardness and chewiness of frankfurters with low (1%) salt content relative to that of control frankfurters with 1.5% salt. Kang, Li, and Ma (2017) observed increased cook yield in frankfurters with addition of TG as well as increased hardness, springiness, cohesiveness, and chewiness. Varying levels of collagen exist in processed meat products based on the anatomical source of meat used as raw material. Because frankfurters and other finely comminuted products (FCMP) are generally produced with lean trim that is not typically sold as retail cuts, the amount of collagen present can be significant. In addition to the collagen present as part of the meat block, isolated, and refined collagen can be added to formulations in order to alter the texture and processing characteristics of FCMP (Schilling, Mink, Gochenour, Marriott, & Alvarado, 2003; Tarté, 2009). Prabhu, Doerscher, and Hull (2004) found that the addition of refined pork collagen significantly increased the PY of pork and chicken frankfurters when added at levels above 1% of the formulation, while Sousa et al. (2017), Petrasova et al. (2018), and Hjelm, Mielby, Gregerson, Eggers, and Bertram (2019) each reported that addition of collagen increased textural hardness and chewiness of frankfurters. These authors attributed their findings to the absorption and binding of water by collagen in the gelled protein matrix.

Thus, the objective of this study was to evaluate the impact of these nonmeat binding agents on the performance of the different processing methods typically used to form comminuted meat batters for the production of frankfurters, and to determine if a specific combination of nonmeat binding agent and processing method might be advantageous for these products.

2 | MATERIALS AND METHODS

2.1 | Materials and methods

Frozen raw meat materials consisting of 50% lean pork and 90% lean beef were obtained from the Iowa State University Meat Laboratory. The frozen meat was allowed to temper at 2.2°C for 3 days. Five treatments of frankfurters with a variety of nonmeat binding agents were formulated. Each formulation was prepared by three different processing methods; as a coarse-ground (CG) batter, or as a finely comminuted batter using either an EM, or a BC. The nonmeat binding agents included iota carrageenan (S-100, Ingredient Solutions, Inc., Waldo, ME, USA), SA (WBS 203, Wenda Ingredients, Naperville, IL, USA), TG (Activa TI, (maltodextrin 99%, TG 1%), Ajinomoto North America, Inc., Ft. Lee, NJ, USA), and a functional pork collagen ingredient in the form of dried pork stock (DPS, Essentia Protein Solutions, Ankeny, IA, USA). The control treatment consisted of a standard Iowa State University frankfurter formulation including salt, spices (EJ-93-150-001, A.C. Legg, Calera, AL, USA), and sodium nitrite, but without phosphates, and with the level of added sodium chloride reduced from 2% to 1.5% of the meat weight. Not including phosphates and reducing the salt concentration were done in order to weaken the emulsion stability to a degree that the adjunct ingredients would have greater opportunity to effectively show signs of improving the stability of the batter. Raw meat materials were formulated to provide a fat content of approximately 30% in the finished frankfurters. Fat analyses of the raw meat materials were performed prior to formulation using an Anyl Ray fat analyzer (Kartridg Pak, Model 316-48, R.A. Jones & Co, Davenport, IA, USA). Formulations for individual ingredient formulations are listed in Table 1. The amount of each of the nonmeat binding ingredients was determined by supplier’s recommendations and by preliminary experiments.

2.2 | Batter and frankfurter production

For each of the five ingredient formulations, production of the frankfurter batters was performed using three separate and independent batter preparation methods which included coarse grinding, chopping in a BC, or passing through an EM. For all treatments and preparation methods, the lean beef portion and the fat pork portion of the meat block were first coarsely ground independently through a 12.7 mm grinder plate prior to creation of the batter.

For treatments containing SA, a unique process was required because alginate does not form gels effectively in the presence of NaCl (Hong & Chin, 2010). In order to avoid the relatively high salt concentrations during blending, the fat portion of the meat block was ground through a 12.7 mm grinder plate the day prior to batter production, and then, mixed with half of the water included in the formulation. Simultaneously, the SA was also incorporated into the water/pork fat mixture. The resulting blend was flattened to a
uniform thickness at the bottom of a storage lug and allowed to rest overnight (15 hr) in a cooler at 2°C to provide the time needed to form a firm gel. This produced a firm “sheet” of pork fat suspended in alginate gel which was sliced into 25 mm cubes by hand prior to being incorporated into the batters.

For the production of the EM and CG treatments, the meat and nonmeat ingredients were mixed into a homogenous pre-blend using a double action ribbon/paddle mixer (Leland Southwest, model 200DA70, Ft. Worth, TX, USA) immediately prior to batter production. The production of the pre-blends was achieved as follows: the lean portion of the meat block was added to the mixer along with the salt and half of the water. Half of the weight of the water was in the form of ice in order to keep the temperature of the pre-blend low during mechanical processing. After mixing for 2 min, the fat portion of the meat block and the remaining nonmeat ingredients (including the ice/water mixture) were added to the blend and allowed to mix for an additional 2 min.

In order to achieve the final CG batters, the pre-blend was passed through a 3.18 mm grinder plate using a table top grinder (Torrey, model M-22R, Houston, TX, USA).

Prior to passing pre-blends through the EM (Stephan Microcut, Mundelein, IL, USA), the mill was first chilled by passing 2 kg of ice through the hopper, knives, and discharge spout of the machine. This process was also performed between each treatment in order to return the contact surfaces of the mill to a consistent temperature.

For treatments processed in the BC, the lean portion of the meat block was first added to the BC (Kilia, Vacuum-Cooking Bowl Cutter 30 L with 6 knives, Neumuenster, Germany) along with the salt and half of the ice/water mixture. The mixture was chopped at a knife speed of 5,400 rpm and a bowl speed of 20 rpm until the mixture reached 5.5°C. The fat portion of the meat block was then added to the BC along with the remaining ice/water mixture and nonmeat ingredients. When chopping the treatment containing the SA, the portion of ice/water mixture was reduced by half in order to compensate for water previously added to hydrate the SA while incorporating it into the fat portion of the meat block. This resulted in 25% of the overall ice/water mixture being added during lean chopping and 25% being added along with the fat portion. This resulted in a more rapid increase in temperature during chopping for the SA treatment, and therefore, a shorter chopping time. With all of the ingredients in the BC, the batter was chopped under vacuum at a knife speed of 5,400 rpm and a bowl rotation speed of 20 rpm until the temperature of the batter reached a temperature of 13°C.

For all of the treatments, once the final comminution of batter was achieved, samples of the raw batter were collected for analysis of emulsion stability. The remaining batter was loaded into a vacuum filler (Risco, Model 4003-165, South Easton, MA, USA), and stuffed in to size 26 (USA) peelable cellulose casings (Viscofan, 651795P 26x125 CF-FP, Lisle, IL, USA). The sausages were linked, placed on sticks, weighed, and all treatments were placed on a single smoke truck for thermal processing. Thermal processing was accomplished using a Maurer, single-truck, batch oven (Maurer-Atmos, Reichenau, Germany) with attached natural smoke generator (Raucherzeuger Goliath II, Reichenau, Germany). The franks were cooked to an internal temperature of 70°C using the cook/natural smoke cycle established for frankfurters at the Iowa State University Meat Laboratory.

### TABLE 1 Frankfurter formulations

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Formulation</th>
<th>Sodium alginate</th>
<th>Iota carrageenan</th>
<th>Transglutaminase</th>
<th>Pork collagen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef trim(^a)</td>
<td>Control</td>
<td>2.87 kg</td>
<td>2.87 kg</td>
<td>2.87 kg</td>
<td>2.87 kg</td>
</tr>
<tr>
<td>Pork trim(^b)</td>
<td>Control</td>
<td>2.87 kg</td>
<td>2.87 kg</td>
<td>2.87 kg</td>
<td>2.87 kg</td>
</tr>
<tr>
<td>Ice/Water</td>
<td>Control</td>
<td>2.00 kg</td>
<td>2.00 kg</td>
<td>2.00 kg</td>
<td>2.00 kg</td>
</tr>
<tr>
<td>Seasoning(^c)</td>
<td>Control</td>
<td>222.3 g</td>
<td>222.3 g</td>
<td>222.3 g</td>
<td>222.3 g</td>
</tr>
<tr>
<td>Salt</td>
<td>Control</td>
<td>136.1 g</td>
<td>136.1 g</td>
<td>136.1 g</td>
<td>136.1 g</td>
</tr>
<tr>
<td>Curing salt(^d)</td>
<td>Control</td>
<td>16.33 g</td>
<td>16.33 g</td>
<td>16.33 g</td>
<td>16.33 g</td>
</tr>
<tr>
<td>Sodium alginate(^e)</td>
<td>CG only</td>
<td>–</td>
<td>81.65 g</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Iota carrageenan(^f)</td>
<td>CG only</td>
<td>–</td>
<td>–</td>
<td>45.36 g</td>
<td>–</td>
</tr>
<tr>
<td>Transglutaminase(^g)</td>
<td>CG only</td>
<td>–</td>
<td>–</td>
<td>6.80 g</td>
<td>–</td>
</tr>
<tr>
<td>Pork collagen(^h)</td>
<td>CG only</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>22.8 g</td>
</tr>
</tbody>
</table>

\(^a\) 90% Lean.
\(^b\) 50% Lean.
\(^c\) EJ-93-150-001-A.C. Legg.
\(^d\) 6.25% NaNO₂.
\(^e\) WBS 203-Wenda Ingredients.
\(^f\) S100-ISI.
\(^g\) Activa TI-Ajinomoto North America.
\(^h\) DPS—Essentia.
Upon completion of thermal processing, the sausages were removed from the oven and placed in a cooler at 0°C to chill overnight (15 hr).

### 2.3 | Processing yield

Once chilled, the frankfurters were reweighed to determine smokehouse and stabilization yield (processing yield, PY). The cellulose casings were removed from the frankfurters using an automated peeler (Townsend Engineering, Model 2600, Des Moines, IA, USA). The franks were then vacuum packaged in bags (Cryovac Sealed Air, 5x16 B2470 Standard, Charlotte, NC, USA) at the rate of five links per pack in a single layer and stored under refrigeration (2°C) for approximately 2 weeks prior to being analyzed for texture.

### 2.4 | Emulsion stability analysis

As previously described, samples of raw batter were collected immediately following the final mechanical steps of batter production, and evaluated using the Rongey method as described by Sebranek, Lonergan, King-Brink, and Larson (2001). A modified, open-end syringe was used to collect an approximate 25 g sample from each batter. The samples were transferred to Wierbicki tubes containing fritted glass discs, with care taken to minimize air bubbles while filling the tube on top of the glass discs. Samples were then cooked in a water bath (Shel Lab, model WP C95, Cornelius, OR, USA) for 30 min at 71.1°C. Upon completion of cooking, samples were allowed to cool at ambient temperature for 3 min. The samples were then placed in a centrifuge (Lab Line, Inc., Model No. 61, Chicago, IL, USA), and spun at low speed (10,000 rpm) for 5 min. After centrifugation, amounts of separated fat and water that collected below the glass discs in the Wierbicki tubes were measured. Percent water separation, percent fat separation, and percent total liquid separation were calculated using the following formulas:

\[
\text{% water separation} = \left( \frac{\text{ml water}}{\text{sample weight}} \right) \times 100
\]

\[
\text{% fat separation} = \left( \frac{\text{ml fat}}{\text{sample weight}} \right) \times 100
\]

\[
\text{% total liquid separation} = \text{% water separation} + \text{% fat separation}
\]

Three samples were analyzed from each ingredient x processing method treatment.

### 2.5 | Texture analysis

Texture analysis was conducted within 2 weeks of packaging the frankfurters. Samples of each treatment were randomly selected from the packaged frankfurters. The frankfurters were stored under refrigeration until just prior to analysis in order to reduce temperature variations. A 2.54 cm cross section was cut from the middle of individual, randomly selected frankfurters for analysis. Texture analysis was conducted using a TA-XT2i Texture Analyzer (Texture Technologies Corp., Algonquin, IL, USA). The tests were performed using a 5.08 cm cylinder probe (model TA-25) to compress the sample along its vertical axis. The texture profile analysis (TPA) test was programed with a trigger force of 5 g, a compression speed of 5 mm/s, travel distance of 50%, and return speed of 5 mm/s. Frankfurters samples were measured by a standard, 2 compression, TPA procedure with a focus on hardness, cohesiveness, and chewiness as the primary data of interest. Hardness was measured as the peak force of the first compression, cohesiveness was measured as the area of work during the second compression divided by the area of work in the first compression, and chewiness was calculated as gumminess multiplied by springiness (Bourne, 2002). Three samples of each ingredient x processing method treatment were tested.

### 2.6 | Statistical analysis

The experiment was independently replicated three times on separate production days for each replication over the course of a six-month period. Statistical analysis of the data was performed using PROC MIXED by Statistical Analysis System (SAS v9.4, Cary, NC). The fixed effects of the experimental process, formulations, and test replication were analyzed. Results were compared for differences among frankfurter treatments as well as for the differences between processing methods. Least square means and standard errors are reported for each characteristic. Significance was determined at \( p \leq .05 \).

### 3 | RESULTS AND DISCUSSION

#### 3.1 | Processing yield

Measurement of PY of the frankfurter formulations using the EM, BC, and coarse ground (CR) processing methods are presented in Table 2. The yields were significantly different (\( p < .05 \)) for each of the three different processing methods, with the EM resulting in greater yield than the CR process in all formulations and greater than the BC for the control and carrageenan (IC) formulations. The CR products resulted in the lowest yield for all formulations except the IC. This can be attributed to the level of comminution and the increase in functional protein extraction and availability produced by the EM and the BC because extracted protein serves to bind free water. No differences between the EM and BC methods were observed for frankfurters prepared with pork collagen (CO), SA, or TG, but IC resulted in greater yield when processed in the EM. Overall, this confirms that the processing method used for final comminution of the batter, particularly the fine comminution achieved by the EM and the BC, is an important determinant of the PY of frankfurters. This is a well-recognized effect of comminution...
on PY for these products. These results also show that adding certain adjunct ingredients has potential to reduce the differences between the processing methods, particularly the EM and BC. Table 2 also displays the results for PY measurements for each of the different frankfurter formulations in the three processing methods. PY of frankfurter formulations IC, SA, and TG produced in the EM were not significantly different ($p > .05$) than the control. At the same time, the TG frankfurters had lower ($p < .05$) PY than the SA and IC frankfurters from the EM but was not different ($p > .05$) from the control or CO frankfurters. These observations are consistent with previous observations where the incorporation of TG reduced the yield of myofibrillar protein gels (Chin, Go, & Xiong, 2009). Of the frankfurters produced in the BC, only the SA formulation was significantly ($p < .05$) different for PY, and resulted in the highest yield compared to all other formulations processed with the BC. No significant differences ($p > .05$) occurred among the other formulations for the BC method. CR treatments containing SA and IC also showed a significant ($p < .05$) increase in PY when compared to all other formulations. Of the four ingredient treatments, SA increased yield most consistently, among the different processing methods used. This is in agreement with Kim, Yong, Jung, Kim, and Ma (2020) who reported greater PY for meat emulsions with added alginate compared with controls. However, the difference in our study may also have been affected by the preparation method necessary for SA in this study as previously described, where a substantial amount of added water was pre-blended with the SA ingredient and allowed to form a gel prior to being incorporated into the final batter. The observed effects of the nonmeat ingredients are similar to observations by Hong and Chin (2010) who reported that SA improved the water-binding ability of porcine myofibrillar gels, and that TG enhanced gel strength but increased moisture loss from the gels. These authors also reported that combining SA and TG treatments was effective for improving both water retention and texture of the protein gels. Sadeghi-Meier, Raudsepp, Bruggemann, Lautenschlaeger, and Drusch (2018) also compared SA and TG in porcine meat batters and reported increased water binding achieved by addition of SA to the batters.

### 3.2 Emulsion stability

The effects of processing method on water separation in the emulsion stability analysis are shown in Table 3. All frankfurter formulation treatments processed in the BC, except the SA treatment, showed significantly less water separation compared to the other processing methods. Table 3 also displays the results for the effect of frankfurter formulation on water separation from the emulsion stability analysis. Control frankfurters processed in the BC showed the greatest numerical amount of water separation, but this was not statistically different ($p > .05$) from CO, IC, or TG. The SA treatment was significantly ($p < .05$) lower than the control, resulting in the least amount of water separation. CR frankfurters showed the greatest amount of water separation.

### Table 2

<table>
<thead>
<tr>
<th>Process</th>
<th>Formulation</th>
<th>Control</th>
<th>Pork collagen</th>
<th>Iota carrageenan</th>
<th>Sodium alginate</th>
<th>Transglutaminase</th>
<th>SE$^d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emulsion mill</td>
<td>87.3$^{AB}$</td>
<td>86.4$^{AB}$</td>
<td>87.8$^{AB}$</td>
<td>87.5$^{AB}$</td>
<td>86.6$^{AB}$</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Bowl chopper</td>
<td>86.3$^{bB}$</td>
<td>86.1$^{bB}$</td>
<td>86.4$^{bB}$</td>
<td>87.6$^{bB}$</td>
<td>86.5$^{bB}$</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Coarse ground</td>
<td>85.0$^{aB}$</td>
<td>85.3$^{aB}$</td>
<td>86.4$^{aB}$</td>
<td>86.8$^{aB}$</td>
<td>85.1$^{aB}$</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>SE$^d$</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^{a-c}$Means in the same column with different letters are significantly different at $p < .05$.

$^{A-C}$Means in the same row with different letters are significantly different at $p < .05$.

$^d$Standard error of means.

### Table 3

<table>
<thead>
<tr>
<th>Process</th>
<th>Formulation</th>
<th>Control</th>
<th>Pork collagen</th>
<th>Iota carrageenan</th>
<th>Sodium alginate</th>
<th>Transglutaminase</th>
<th>SE$^d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowl chopper</td>
<td>2.7$^{A}$</td>
<td>2.0$^{AB}$</td>
<td>1.9$^{AB}$</td>
<td>1.6$^{B}$</td>
<td>2.1$^{AB}$</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Coarse ground</td>
<td>10.2$^{bB}$</td>
<td>15.0$^{bA}$</td>
<td>5.6$^{bC}$</td>
<td>7.7$^{bC}$</td>
<td>11.0$^{bB}$</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Emulsion mill</td>
<td>9.1$^{A}$</td>
<td>8.4$^{AB}$</td>
<td>6.7$^{bB}$</td>
<td>2.3$^{bC}$</td>
<td>10.1$^{AB}$</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>SE$^d$</td>
<td>0.8</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^{a-c}$Means in the same column with different letters are significantly different at $p < .05$.

$^{A-C}$Means in the same row with different letters are significantly different at $p < .05$.

$^d$Standard error of means.
when formulated with CO and the least when formulated with IC and SA, respectively, while frankfurters produced in the EM also showed the lowest water separation values when formulated with SA.

The results for the effects of frankfurter processing method on fat separation during emulsion stability analysis are shown in Table 4. The amount of fat separation was relatively small in all cases, consequently differences were difficult to detect. The BC generally resulted in less fat separation, but this was significant only with the IC and TG formulations. The ground product generally resulted in the greatest fat separation but again, this was significant only for the CO and SA formulations. IC and TG treatments produced in the EM showed similar results to the same treatments produced by coarse grinding. Also shown in Table 4 is the effect of the frankfurter formulations on the fat separation component of emulsion stability analysis. Here again, the relatively small amount of fat separation that occurred in all cases makes any potential differences difficult to detect. While SA resulted in significantly less (p < .05) fat separation than the other nonmeat binding agents in the EM, it was not different than the control. Results reported in the literature for the impact of these nonmeat ingredients on emulsion properties are variable. Kim et al. (2020) reported that a meat emulsion with alginate was more stable than the control in terms of separated water and fat. On the contrary, Hong, Min, and Chin (2012) indicated that alginate destabilized a pork protein emulsion while TG resulted in greater emulsion capacity. Our results suggest that formulation with nonmeat binders has minimal effect on fat separation from meat batters as observed in the different processing methods used in this study. However, these results are most likely due to relatively stable emulsions in all of the treatments in this study where little fat separation occurred in all cases.

3.3 | Texture analysis

Results for the effects of processing method on the TPA component of hardness are displayed in Table 5. The three processing methods were similar (p > .05) in hardness to that of the control formulation. Further, no significant differences (p > .05) between processing methods were observed for the frankfurters formulated with CO or TG. CR frankfurters formulated with either IC or SA were similar to each other but with less (p < .05) hardness than those produced in the EM. Frankfurters formulated with IC or SA and produced in the BC were not significantly different (p > .05) than those produced in the EM or that were CR. Table 5 also shows the results of the effect of frankfurter formulation on TPA hardness. No significant (p > .05) differences were seen between any of the formulations that were produced in the BC. The TG formulation, although not different from CO, was significantly (p < .05) harder than the control, IC or SA in the CR frankfurters. The frankfurters produced in the EM with the CO formulation were similar to the control, but the SA, IC, and TG formulations were significantly (p < .05) harder.

### Table 4 Least squares means for the effect of frankfurter formulation and processing method on emulsion stability analysis—fat separation (%)

<table>
<thead>
<tr>
<th>Process</th>
<th>Formulation</th>
<th>Control</th>
<th>Pork collagen</th>
<th>Iota carrageenan</th>
<th>Sodium alginate</th>
<th>Transglutaminase</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowl chopper</td>
<td></td>
<td>0.5bA</td>
<td>0.5bA</td>
<td>0.5bA</td>
<td>0.4bA</td>
<td>0.5bA</td>
<td>0.1</td>
</tr>
<tr>
<td>Coarse ground</td>
<td></td>
<td>1.8aAB</td>
<td>2.3aA</td>
<td>1.3aAB</td>
<td>1.8aAB</td>
<td>1.2aB</td>
<td>0.2</td>
</tr>
<tr>
<td>Emulsion mill</td>
<td></td>
<td>1.2aAB</td>
<td>1.3aA</td>
<td>1.4aA</td>
<td>0.5bB</td>
<td>1.7aA</td>
<td>0.2</td>
</tr>
<tr>
<td>SE</td>
<td></td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

a–bMeans in the same column with different letters are significantly different at p < .05  
A–BMeans in the same row with different letters are significantly different at p < .05.

cStandard error of means.

### Table 5 Least squares means for the effect of frankfurter formulation and processing method on TPA—hardness (g)

<table>
<thead>
<tr>
<th>Process</th>
<th>Formulation</th>
<th>Control</th>
<th>Pork collagen</th>
<th>Iota carrageenan</th>
<th>Sodium alginate</th>
<th>Transglutaminase</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowl chopper</td>
<td></td>
<td>11.497aA</td>
<td>10.969aA</td>
<td>12.957aA</td>
<td>11.295aB</td>
<td>13.396aA</td>
<td>890.4</td>
</tr>
<tr>
<td>Coarse ground</td>
<td></td>
<td>9.817aB</td>
<td>11.715aAB</td>
<td>9.755bB</td>
<td>10.030bB</td>
<td>13.829aA</td>
<td>918.2</td>
</tr>
<tr>
<td>SE</td>
<td></td>
<td>717.65</td>
<td>802.62</td>
<td>1,006.53</td>
<td>784.13</td>
<td>314.1</td>
<td></td>
</tr>
</tbody>
</table>

a–cMeans in the same column with different letters are significantly different at p < .05.

A–BMeans in the same row with different letters are significantly different at p < .05.

cStandard error of means.
reported that TG increased the hardness of frankfurters, and other researchers (Sousa et al., 2017) have reported greater hardness with addition of collagen to frankfurters.

Results for the effect of processing methods on the TPA component of chewiness are displayed in Table 6. The ingredient formulations produced in the BC and in the EM, each produced statistically similar (p > .05) results. Values observed in all formulations produced by coarse grinding were significantly lower (p < .05) for chewiness than for batches produced in the EM or BC. This is likely due to the reduced protein extraction and subsequent adhesion between CR particles resulting from the reduced mechanical action that occurs with coarse grinding in comparison to the protein gel matrix that results from finely comminuted meat mixtures. Table 6 also shows results for the effect of frankfurter formulation on the TPA component chewiness. The TG formulation resulted in the highest (p < .05) value for chewiness in the CR frankfurters, and also resulted in a trend toward greater numerical value for chewiness with the other processing methods, though this was not significantly (p > .05) different from the other ingredients, in most cases. In general, with formulations produced in the EM, the IC, SA, and TG treatments showed significant improvement in chewiness over the control. The protein crosslinking effect of TG appears to have had a greater impact on the loosely structured CR particles than in the case of the finely FCMP where the protein gel matrix is more predominant. Because chewiness as well as cohesiveness are indications of the expected effort required for mastication of the sausage, these measures reflect the amount of protein crosslinking and binding between meat particles that occurs in the product, and are properties generally considered desirable for finely comminuted processed meats such as frankfurters.

The concept of a more loosely held product structure in the CR products is supported by the results for the TPA component of cohesiveness, shown in Table 7. All coarsely ground formulations resulted in significantly (p < .05) less cohesiveness, while the BC and the EM were similar for all the formulations. Also in Table 7, the effect of frankfurter formulation on cohesiveness shows that the TG formulation produced in the BC resulted in a significant (p < .05) increase in cohesiveness compared to the other formulations, which did not differ from each other. In treatments produced in the EM, the SA and TG formulations increased (p < .05) the cohesiveness relative to the control. Thus, SA and TG have potential to impact product cohesiveness of meat batters but the impact is dependent on the processing method used.

<table>
<thead>
<tr>
<th>Process</th>
<th>Formulation</th>
<th>Control</th>
<th>Pork collagen</th>
<th>Iota carrageenan</th>
<th>Sodium alginate</th>
<th>Transglutaminase</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowl chopper</td>
<td>6,223.72&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>5,971.40&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>7,026.28&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>6,174.44&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>8,043.20&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>496.3</td>
<td></td>
</tr>
<tr>
<td>Coarse ground</td>
<td>3,526.50&lt;sup&gt;BBC&lt;/sup&gt;</td>
<td>4,124.31&lt;sup&gt;BBC&lt;/sup&gt;</td>
<td>3,305.93&lt;sup&gt;BBC&lt;/sup&gt;</td>
<td>2,423.50&lt;sup&gt;BBC&lt;/sup&gt;</td>
<td>5,854.47&lt;sup&gt;BBC&lt;/sup&gt;</td>
<td>364.4</td>
<td></td>
</tr>
<tr>
<td>Emulsion mill</td>
<td>6,035.15&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>6,434.11&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>6,907.90&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>7,218.53&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>7,442.34&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>146.3</td>
<td></td>
</tr>
<tr>
<td>SE&lt;sup&gt;c&lt;/sup&gt;</td>
<td>306.68</td>
<td>460.38</td>
<td>358.92</td>
<td>438.35</td>
<td>280.57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a–b</sup>Means in the same column with different letters are significantly different at p < .05.

<sup>A–C</sup>Means in the same row with different letters are significantly different at p < .05.

<sup>c</sup>Standard error of means.

<table>
<thead>
<tr>
<th>Process</th>
<th>Formulation</th>
<th>Control</th>
<th>Pork collagen</th>
<th>Iota carrageenan</th>
<th>Sodium alginate</th>
<th>Transglutaminase</th>
<th>SE&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowl chopper</td>
<td>64.41&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>64.90&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>64.18&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>64.87&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>68.93&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Coarse ground</td>
<td>46.38&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>44.60&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>41.07&lt;sup&gt;BBC&lt;/sup&gt;</td>
<td>31.38&lt;sup&gt;BBC&lt;/sup&gt;</td>
<td>51.88&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Emulsion mill</td>
<td>59.72&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>62.54&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>62.50&lt;sup&gt;BBC&lt;/sup&gt;</td>
<td>64.01&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>66.33&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>SE&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a–b</sup>Means in the same column with different letters are significantly different at p < .05.

<sup>A–C</sup>Means in the same row with different letters are significantly different at p < .05.

<sup>c</sup>Standard error of means.

4 | CONCLUSIONS

The results of this study support the widely accepted understanding that, for sausage products such as frankfurters, a greater degree of comminution will result greater technological quality which translates to greater yield and a firmer texture. For example, coarse grinding will result in reduced emulsion stability, reduced product...
yield, and less cohesive texture. Consequently, the BC and the EM processes both result in products with greater yield and firmer texture than coarse grinding, as might be expected, given that the coarse grinding process was included in this study to provide contrast between the processing methods. Iota carrageenan and SA are recognized as water-binding ingredients and both offer potential to increase batter stability and yield for frankfurter-style products, with the degree of impact dependent on the comminution method chosen. TG, on the contrary, does not improve moisture retention of these products despite the fact that product cohesiveness is generally increased due to the crosslinking of proteins achieved by this ingredient. Consequently, the best approach that offers potential for improving yield and texture of comminuted sausage products and to maximize technological quality of these products is to use either a BC or an EM with a combination of either iota carrageenan or SA with transglutaminase.

ACKNOWLEDGMENTS
This study was supported by funds from the endowment for the Morrison Chair in Meat Science at Iowa State University awarded to Dr. Joseph Sebranek.

CONFLICT OF INTEREST
The authors have declared no conflicts of interest for this article.

REFERENCES


How to cite this article: Ruther BL, Dickson JS, Prusa KJ, Tarté R, Sebranek JG. Effects of processing method and nonmeat binding ingredients on batter stability, yield and texture of frankfurters. *J Food Process Preserv*. 2020;00:e14626. https://doi.org/10.1111/jfpp.14626