Replacement of pork fat in frankfurter-type sausages by soybean oil oleogels structured with rice bran wax

Taylor L. Wolfer, Nuria C. Acevedo, Kenneth J. Prusa, Joseph G. Sebranek, Rodrigo Tarté

Abstract

The objective of this study was to assess the impact of replacing pork backfat with rice bran wax oleogels on the organoleptic properties of frankfurter-type finely-comminuted sausages. Frankfurters were formulated using the following treatments as lipid replacement: 1) pork fat (PF); 2) soybean oil (SBO); 3) 2.5% rice bran wax oleogel (2.5 RBW); 4) 10% rice bran wax oleogel (10 RBW); and 5) 2.5% rice bran wax oleogel sheared less during frankfurter production (RBW/LS). In general, control PF was darker and redder than other treatments. TPA revealed oleogel treatments to be similar (P > .05) to pork fat treatment for firmness, chewiness, and springiness. Additionally, sensory evaluation revealed that replacing pork fat did not influence cured frankfurter aroma, but cured frankfurter flavor was significantly reduced (P < .05). Furthermore, lipid oxidation significantly (P < .05) differed between PF and 10 RBW. The results show that rice bran wax oleogels have the potential to successfully replace pork fat in comminuted products.

Introduction

Fats and oils are critical for both human health and food quality. The 2015–2020 Dietary Guidelines for Americans (2015) recommends 30% of caloric intake from fats and oils, with most of that energy consumption in the form of unsaturated fatty acids. These recommendations align with much of the modern literature that agrees unsaturated fatty acids and polyunsaturated fatty acids are important for reducing biomarkers for cardiovascular disease (Dyerberg et al., 2004), reducing plasma cholesterol (Vafeiadou et al., 2015), increasing satiation (Maljaars, Romeyn, Haddeman, Peters, & Masclee, 2009), and decreasing inflammatory cytokines (Han et al., 2002).

All these health benefits are overcome by the fact that meat processors rely heavily on highly-saturated animal fat to give their products the proper texture and flavor. Substitution of animal fat with vegetable oil in finely-comminuted products can lead to increased hardness and chewiness (Youssef & Barbut, 2010; Zetzl, Marangoni, & Barbut, 2012), as well as lighter and less red color (Álvarez et al., 2011; Youssef & Barbut, 2010). Furthermore, lipid oxidation is increased when saturated fat is replaced with unsaturated fat, but this is not a practical concern in cured meat products because of the potent antioxidant capabilities of sodium nitrite (Álvarez et al., 2011; Berasategi et al., 2014). Replacement of fat with vegetable oil in comminuted products can also result in processing challenges such as increased greasy residue on processing equipment (Baer & Dilger, 2014), and decreased emulsion stability in finely-comminuted products (Álvarez et al., 2011; Youssef & Barbut, 2010). Animal fat is a fundamental ingredient in processed meat products and, as such, is difficult to replace.

Oleogels, gels in which the liquid phase is oil, are a relatively novel fat replacement technology. They provide both the nutritional benefits of oils (Storz, Zet, Barbut, Cattaruzza, & Marangoni, 2012), and the positive organoleptic and technological attributes of harder, more saturated fats (Barbut, Wood, & Marangoni, 2016b; Barbut, Wood, & Marangoni, 2016b; Zetzl et al., 2012). Oleogels require a gelling molecule that can stack into an organized scaffold in order to structure the vegetable oil (Marangoni & Garti, 2011). One such source of gelling molecule is rice bran wax. Rice bran wax has been shown to produce an oleogel at 1:99 rice bran wax:liquid oil (Blake, Co, & Marangoni, 2014; Dassanayake, Kodali, Ueno, & Sato, 2012). Oleogels made with 10% rice bran wax can be firm and brittle, despite a solid fat content of < 7%. Rice bran wax oleogels increase in melting temperature as the
concentration of rice bran wax increases. Dassanayake, Kodali, Ueno, and Sato (2009) reported the melting temperature of oleogels produced with 1%, 3%, 5%, and 10% rice bran wax to be 54.3 °C, 57.8 °C, 60.8 °C, and 65.2 °C, respectively. In addition to the concentration of the gelling agent, other oleogel manufacturing variables, such as cooling rate, type of gelling agent, and length of storage time, can influence the melting temperature and firmness of the final oleogel (Dassanayake et al., 2009; Dassanayake et al., 2012; Toro-Vazquez et al., 2007).

There has been very little research on the use of oleogels in food products, and even less within processed meats. Zetzl et al. (2012) and Barbut et al. (2016a), utilized ethylcellulose and canola oil to create oleogels for a partial fat replacement in beef frankfurters. Replacing animal fat with oleogels resulted in frankfurters with intermediate characteristics to those produced with animal fat and those produced with native canola oil. Moreover, replacing beef fat with ethylcellulose oleogel improved cook yields (Barbut et al., 2016b).

No research has studied rice bran wax oleogels as a potential animal fat replacement in pork frankfurters. This study is also unique in that it is the only known study that tracks the shelf-life of meat products containing oleogels. Additionally, no known research has attempted to use oleogels to replace nearly all of the animal fat in the product.

It should be noted that rice bran wax, though listed as GRAS (Generally Recognized as Safe) in the United States, is presently only approved as a coating in candy, fresh fruits and fresh vegetables, and as a plasticizer in chewing gum. (Rice Bran Wax, 2017), Approval has not been petitioned for its use in other food products, so therefore it isn’t currently approved as an ingredient in meat products. It was chosen for this study because it gels oil effectively at low concentrations (Blake et al., 2014; Dassanayake et al., 2012), produces a white gel with a fat-like appearance, and is relatively inexpensive compared to other potential gelators. Demonstration of its effectiveness as a functional ingredient for other food applications could awaken interest and lead to the reconsideration of its regulatory status as a meat and food ingredient.

It is hypothesized that oleogels produced with rice bran wax and soybean oil will result in pork frankfurters with processing characteristics and texture attributes similar to those of frankfurters produced with animal fat. The objective of this research is to characterize the impact of oleogels as an animal fat replacement on processing characteristics, texture, color, lipid oxidation, and sensory properties over time.

2. Materials & methods

2.1. Oleogel preparation

Based on subjective firmness, appearance, and flavor, two different concentrations of rice bran wax, 2.5% and 10% wt/wt, were evaluated for oleogel production. Correct amounts of soybean oil (ADM Grain Eastern Trading, Decatur, IL, USA) and rice bran wax (Koster Keunen, Inc., Watertown, CT, USA) were weighed and mixed in a 7.57-L stainless steel bowl and placed in a 121 °C convection oven (Model #LEGF304SKFJ, Frigidaire, Charlotte, NC, USA). After achieving the target temperature of 90 °C, which required approximately 2 h, solutions were stirred every 7 min for 30 min before being removed from the oven.

The stainless steel bowls were then covered with aluminum foil and stored at 2.7 °C. Cooling rate was determined by placing a temperature logger in the geometric center of the oleogel solution. The average cooling rate for the three replications was −1.44 °C min−1. Two 2.5% rice bran wax oleogels and one 10% rice bran wax oleogel were made for each replication. Oleogels were prepared 5–7 d prior to use in frankfurters to ensure proper setting of the gel matrix.

2.2. Frankfurter preparation

2.2.1. Frankfurter materials and formulations

Five frankfurter treatments were produced using the following lipid replacements or strategies: 1) pork back fat (PF); 2) soybean oil (SBO); 3) oleogel produced with soybean oil and 2.5% rice bran wax (2.5 RBW); 4) oleogel produced with soybean oil and 10% rice bran wax (10 RBW); and 5) oleogel produced with soybean oil and 2.5% rice bran wax added later in the bowl-chopping step of the frankfurter batter (RBW/LS) in order to reduce the amount of shear applied to the oleogel.

Trimmed pork knuckles and pork backfat were obtained from a commercial meat packing plant. Upon receipt at the Iowa State University Meat Laboratory, the raw meat materials were immediately stored at −1 °C for no longer than 5 d and analyzed for proximate composition (Table 1). All meat raw materials and nonmeat ingredients used in all three replications were from the same production lot, except for lipid source.

Trimmed pork knuckles were used in all treatments to reduce the amount of fat derived from the lean trimmings. This allowed for maximum animal fat replacement using oleogels while still maintaining a final lipid content similar to that commercial frankfurters. Frankfurter batters were formulated to target a lipid content of 18.16%. There was an anticipated cook/chill yield of 88%; so theoretical lipid content in the final product was 20.6%. Meat block was 73% for all treatments. The 2.5 RBW and RBW/LS treatments used the same type of oleogel, but the frankfurters were processed differently, which will be explained in the next section.

2.2.2. Frankfurter processing

Frankfurters were made in the Iowa State University Meat Laboratory, Ames, IA, according to the treatment formulas shown in Table 2. The meat block for each treatment batch weighed 13.61 kg, and total batch weight was 18.55 kg. On the day of production, whole pork knuckles and pork backfat were pre-ground through a 9.53-mm grinder plate. Oleogels and soybean oil were not pre-ground. For the PF, SBO, 2.5 RBW, and 10 RBW treatments, ground knuckles and water/ice were added to a bowl chopper (Krämer & Grebe VSM65, Biedenkopf, Germany) with salt, phosphate, dextrose, curing salt, cure accelerator, and spices, and were chopped under vacuum. After the batter reached 4.4 °C, the lipid source corresponding to each treatment (pork backfat, soybean oil, 2.5% RBW oleogel, or 10% RBW oleogel)
was added, and chopping under vacuum continued until a temperature of 13 °C was reached. For the RBW/LS treatment, the ground knuckles, water/ice, salt, phosphate, dextrose, curing salt, cure accelerator, and spices were chopped under vacuum until the batter reached a temperature of 10 °C, after which the 2.5% RBW oleogel was added, and chopping under vacuum continued until a temperature of 13 °C was reached. The purpose for this treatment was to reduce the amount of mechanical shear applied to the oleogel.

Batters were immediately removed from the bowl chopper and stuffed into 25-mm peelable cellulose casings (Viscofan, Danville, IL, USA) using a vacuum stuffer (Handtmann VF 608 Plus, Lake Forest, IL USA), to a target volume of 56.0 cm³. Stuffed frankfurters were hung on metal dowels, weighed, placed on an oven tree, and cooked in a single-tree Alkar oven (DEC International, Inc., Lodi, WI, USA) following the thermal processing cycle shown in Table 3. Treatment processing order and location of treatments on the oven tree were randomized within each replication. Hickory smoke was generated by pyrolyzing natural hickory chips (Chips n’ Chunks Hickory All Natural Wood Chips, Smokehouse Products LLC, Hood River, OR, USA) in a natural smoke generator (Alkar Smokemaster, DEC International Inc., Lodi, WI, USA).

At the end of the second smoke step, a temperature probe was inserted into the geometric center of a frankfurter located near the coolest spot in the smokehouse. Frankfurters were cooked according to the requirements of Appendix A—Compliance Guidelines for Meeting Lethality Performance Standards for Certain Meat and Poultry Products (United States Department of Agriculture/Food Safety and Inspection Service [USDA/FSIS], 1999a) and chilled according to the requirements of Appendix B—Compliance Guidelines for Cooling Heat-Treated Meat and Poultry Products (Stabilization) (USDA/FSIS, 1999b).

Frankfurters were stored overnight in a −1.1 °C cooler and weighed to obtain yields the following morning. Casings were removed using an automatic sausage peeler (Townsend 2600, Townsend Engineering, Des Moines, IA, USA). Prior to packaging, frankfurters were randomized within treatments by mixing in a tub. For packaging, 8 frankfurters per bag were placed inside 4-in × 10-in plastic bags (oxygen transmission rate = 3.6 cm³/m²/24 h at 23 °C, 0% RH; Cryovac Sealed Air Corp., Duncan, SC, USA) and vacuum-sealed (Ultravac UV 2100, UltraSource LLC, Kansas City, MO, USA). Packages were shrink-wrapped in a hot water bath, placed in cardboard boxes, and stored at −1.1 °C.

### 2.3. Frankfurter analysis

#### 2.3.1. Emulsion stability

Emulsion stability was measured using the method of Rongey (1965). This method is dependent on the use of a Wierbicki tube, developed by Wierbicki, Cahill, and Deatherage (1957). Wierbicki tubes are clear cylindrical tubes with a wider diameter on top which quickly tapers to a graduated, small-diameter cylinder on the bottom. A fritted glass disc rests on the bottom of the large diameter area to separate the two compartments. Approximately 25 g of raw frankfurter batter were placed into a Wierbicki tube. Filled Wierbicki tubes were cooked in a 71 °C water bath for 30 min and then centrifuged at 150 rpm for 10 min. Two samples per treatment were analyzed and the results were averaged. Loss of lipid was negligible for all samples, so all loss is assumed to be from moisture. Emulsion stability was calculated as follows:

\[
\text{% Emulsion Stability} = \left[ 1 - \frac{\text{fluid loss}}{\text{sample weight}} \right] \times 100
\]

#### 2.3.2. Proximate analysis

Proximate analysis of finished frankfurters was performed on day 56 of shelf life in accordance with AOAC International procedures. Moisture was determined by method 950.46 (AOAC International, 2005a), fat by method 960.39 (AOAC International, 2005b), and protein by method 992.15 (AOAC International, 2005c) using a TruMac N combustion nitrogen/protein analyzer (Leco Corp., St. Joseph, MI, USA). Samples were tested in triplicate, and the values were averaged for each sample.

#### 2.3.3. Fatty acid profile

Fatty acids were extracted from frankfurter samples and methylated by a one-step direct transesterification procedure, as described by Lepage and Roy (1986). The fatty acid profile was then determined by gas chromatography using a gas chromatograph (GC; Model 3800, Varian Analytical Instruments Inc., Walnut Creek, CA) equipped with an automatic injector (CP 8400/8410, Varian Analytical Instruments Inc.), a 100 m × 0.25 mm (df = 0.20 μm) cyanosiloxane fused silica capillary column (Supelco SP-2380, Sigma-Aldrich Co., LLC, St. Louis, MO, USA) and a flame ionization detector. Helium was used as the carrier gas. Injector and detector temperatures were both maintained at 220 °C. The oven was initially held at 70 °C for 4 min, after which the temperature was raised to 175 °C at 13 °C/min, held at that temperature for 27 min, and then heated to a final temperature of 215 °C at 4 °C/min. One μL of fatty acid methyl ester (FAME) sample was injected into the GC with a split ratio of 99:1. FAME peaks were identified and quantified by evaluating against FAME reference standard GLC-461 (Nu-Chek Prep, Inc., Elysian, MN, USA) (Kramer, Hernandez, Cruz-Hernandez, Kraft, & Dugan, 2008). Iodine values (IV) were calculated according to Recommended Practice Cd 1c-85 of the American Oil Chemists' Society (AOCS, 2017). Frankfurter samples from all three replications were analyzed in duplicate.

#### 2.3.4. TBA analysis

Lipid oxidation of frankfurters was measured on days 0, 14, 28, 42, 56, 70, 84, and 98. Lipid oxidation was determined by a modified 2-thiobarbituric acid (TBA) method for cured products, modified from Zipser and Watts (1962). Absorbance was measured at 532 nm using a spectrophotometer (Model 4,320,940, DU 640, Beckman Instruments, Inc., Fullerton, CA, USA). Analysis was performed in duplicate and results were averaged.

#### 2.3.5. Instrumental color analysis

Internal color was measured on days 0, 14, 28, 42, 56, 70, 84, and 98. The frankfurters were sliced lengthwise, and the cut edge was placed against the 12.7-mm aperture of a LabScan XE spectrocolorimeter (Model 4,320,940, DU 640, Beckman Instruments, Inc., Fullerton, CA, USA) using illuminant D65 (daylight at 6500 K) and a 10° observer angle. CIE L°, a° and b° values were recorded. Three frankfurters per treatment per day were analyzed and averaged.

#### 2.3.6. Texture analysis

Texture analysis and incisor puncture analysis were done using a TA-XT2i Texture Analyzer (Texture Technologies Inc., Scarsdale, NY, USA) on days 0, 14, 28, 42, 56, 70, 84, and 98. Frankfurters were equilibrated to room temperature for approximately 5 h prior to texture analysis. Texture profile analysis (TPA) utilized a 5.08 cm (diameter) ×
20 mm (height) cylindrical aluminum probe (TA-25, Texture Technologies Inc., Scarsdale, NY, USA). The test was performed on 2.54-cm sections of frankfurters which were cut from the center of each frankfurter. Test speed was 5 mm/s and the samples were compressed to 50% of their original height. A two-stroke compression test was used to determine firmness, adhesiveness, resilience, cohesiveness, chewiness, and springiness. TPA was carried out in triplicate and the values were averaged.

Incisor puncture analysis utilized a 9.53-mm incisor blade probe (TA-45, Texture Technologies Inc., Scarsdale, NY, USA) to measure the force required to puncture the surface of the frankfurters. The test was conducted on 6.35-cm sections of frankfurters which were cut from the center, and were positioned such that the incisor probe punctured the center of the sample perpendicular to the length of the frankfurter. The probe descended at a speed of 3.3 mm/s, and the probe inserted into the frankfurter a distance of 15 mm. Incisor puncture analysis was carried out in triplicate and the values were averaged.

2.3.7. Sensory analysis

Each replication was evaluated using a sensory panel at four points during the shelf-life: days 42, 56, 70, and 84. Frankfurters were prepared by boiling 1.42L of water, adding 8 frankfurters from a single package, and returning the water to a boil. After the water containing the frankfurters returned to a boil, the pots were covered and removed from the heat source. After 7 min, the frankfurters were removed from the water and sliced into 12.7-mm cylindrical pieces. End pieces were discarded.

Ten trained panelists were used to evaluate frankfurters for organoleptic properties. Panelists consisted of graduate students, faculty, and staff of the Iowa State University Animal Science and Food Science departments and were selected based on their sensory acuity and availability. Panel training consisted of three separate sessions, at which frankfurters produced for this study were used.

Frankfurters were evaluated on an unstructured 15-point line scale for the following sensory attributes: cured frankfurter aroma, cured frankfurter flavor, chewiness, firmness, off-flavor, exterior darkness, and interior darkness and pinkness. The scales were anchored with terms that represented a low degree of the attribute on the left end of the line and a high degree of the attribute on the right end of the line. Data was collected using Compusense five Release 5.6 sensory evaluation software (Compusense Inc., Guelph, ON, Canada). Panelists were presented with two pieces per treatment and asked to bite through the cut end of the frankfurter, using the molar to determine texture attributes. Treatment order was randomized each session and samples were assigned a random three-digit blinding code before being presented to the panelists.

The sensory analysis protocol was reviewed and approved by the Iowa State University Institutional Review Board and informed consent was obtained from all sensory panel participants prior to initiation of the experiment.

2.3.8. Microstructure

Frankfurter samples were sectioned into slices 10μm in thickness using a Leica CM1850 cryostat (Leica Biosystems, Wetzlar, Germany). Slices were placed on 25 × 75 × 1 mm FisherBrand glass slides (Model #12-552-3, Fisher Scientific, Waltham, MA, USA) and stained with toluidine blue stain for proteins. A cover slip was placed over the sample and magnified at 10 × using a light microscope (Olympus BX40, Olympus Corporation, Tokyo, Japan). Micrographs were collected using AxioVision Microscopy LE software (Release 4.8, Carl Zeiss AG, Oberkochen, Germany). One frankfurter per treatment was observed, and ten images were taken from each frankfurter. Images were analyzed for size and frequency of fat globules using ImageJ image processing software (ImageJ for Windows, 64-bit Java 1.6.0_112, NIH).

2.3.9. Statistical analysis

The study was replicated three times, with each replication corresponding to a different manufacturing day. All raw materials (meats and nonmeat ingredients) for all replications, except for lipid sources, were from the same production lot in order to reduce experimental error by minimizing within block variation. Data were analyzed using PROC MIXED by the Statistical Analysis Software (v9.4, SAS Institute, Cary, NC, USA). The model used treatment, replication, time, and treatment × time interaction as fixed effects, and replication × treatment interaction as the random effect. In the case of sensory analysis, panelists and test sessions were treated as random effects. The random effect was accounted for using an autoregressive error model. Differences between treatments and within treatments over time were determined using the Tukey-Kramer pairwise comparison method with significance at P < .05. Time and treatment × time interaction did not influence color, instrumental texture values, or sensory data; as such, the different time points for these attributes were averaged and a single value was reported.

3. Results & discussion

3.1. Proximate analysis, yields, fatty acid composition and emulsion stability

Proximate composition of frankfurters made with various lipid sources is shown in Table 4. All treatment formulas had a fixed meat block of 73% and were designed to target a lipid content of 21% in the final product, based on prior analysis of the meat raw materials used and an expected cook and chill yield of 88%. Because of the mathematical impossibility of achieving the same fat, moisture and protein contents in treatments that use lipid sources of different composition, the observed slightly lower (P < .05) protein content in PF was expected. With this in mind, all final product analytical values were within the expected range.

Fatty acid profiles are shown in Table 5. These are very much in line with what would be expected based on the lipid source. Compared to the pork fat control (PF), all soybean oil-containing treatments were considerably higher in the essential polyunsaturated fatty acids linoleic (18:2n6) and α-linolenic (18:3n3), and lower in the saturated fatty acids stearic (18:0) and palmitic (16:0) and the monounsaturated oleic (18:1n9). Although neither soybean oil nor pork fat contain the nutritionally-desirable n-3 fatty acids docosahexaenoic (22:6n3) and docosapentaenoic (22:5n3), the soybean oil-containing treatments still exhibited a much lower n-6:n-3 fatty acid ratio (6.48–7.04 vs. 22.85 for pork fat control), which falls more in line with current dietary governmental recommendations (USHHS/USDA, 2015).

Pork fat, soybean oil, and oleogels did not negatively influence the technological quality of the raw frankfurter batter, as indicated by high emulsion stability values (Table 4). The purge which separated from the cooked emulsions when conducting emulsion stability analysis

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Means for effect of treatment on moisture, lipid, protein, emulsion stability, and cook/chill yield.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture (%)</td>
</tr>
<tr>
<td>PF</td>
<td>60.25&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SBO</td>
<td>59.35&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2.5 RBW</td>
<td>59.48&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>10 RBW</td>
<td>59.68&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>RBW/LS</td>
<td>59.64&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>S.E.M.</td>
<td>0.58</td>
</tr>
</tbody>
</table>

<sup>a</sup>c Different superscripts within columns indicate significant differences (P < .05).

S.E.M.: standard error of mean.
Frankfurters produced with pork fat were redder than all other treatments. PF internal a* value was significantly (P < .05) darker than all other treatments, as indicated by a lower L* value. Frankfurters produced with pork fat were redder than all other treatments. PF internal a* value was significantly (P < .05) greater than in frankfurters produced with soybean oil and oleogels. Replacing pork fat with either oleogels or soybean oil did not change the yellowness of the frankfurters, and RBW/LS was significantly (P < .05) more yellow than 2.5RBW and SBO. Álvarez et al. (2011) noted that replacing pork backfat with canola oil and olive oil resulted in frankfurters which were lighter, less red, and more yellow, according to L*, a*, and b* measurements. Similarly, Panagiotopoulou, Moschakis, and Katsanidis (2016), showed that replacing pork backfat in frankfurters with oleogels made with sunflower oil and γ-oryzanol and phytosterols produced lighter, less red frankfurters. Additionally, Barbut et al. (2016a) reported that 70% of beef fat replacement in frankfurters with ethylcellulose oleogels resulted in a reduction in the redness of the frankfurters, and Barbut et al. (2016b) showed that redness was reduced when as little as 20% of the beef fat replacement in frankfurters with ethylcellulose oleogels resulted in a reduction in the redness of the frankfurters, and RBW/LS was significantly (P < .05) more yellow than 2.5RBW and SBO. Additionally, Barbut et al. (2016b) also observed an increased brightness of frankfurters when as little as 20% of beef fat was replaced in frankfurters with ethylcellulose oleogels. Replacing pork fat with either oleogels or soybean oil did not change the yellowness of the frankfurters, and Barbut et al. (2016b) showed that redness was reduced when as little as 20% of the beef fat replacement in frankfurters with ethylcellulose oleogels resulted in a reduction in the redness of the frankfurters, and Barbut et al. (2016b) also observed an increased brightness of frankfurters when as little as 20% of beef fat was replaced with ethylcellulose oleogels, but Barbut et al. (2016a) did not observe this change of L* value. This difference between these two studies could be due to the use of sorbitan monostearate as a surfactant in Barbut et al. (2016b). For sensory color evaluation, PF was confirmed as darker and pinker than all other treatments (P < .05), with the exception of RBW/LS. Internally, PF was determined to be pinker than all other treatments and darker than SBO, 2.5 RBW, and 100RBW. For external color, sensory panelists concluded that PF was darker than all other treatments.

Sensory internal color evaluation aligned with instrumental color yellowness between treatments, as well. There was no difference in internal L* values between PF and RBW/LS; however, PF was significantly (P < .05) darker than all other treatments, as indicated by a lower L* value.

Table 6 shows the values for instrumental and sensory color evaluation. There were no differences in time or a treatment × time interaction for color values; therefore, the data from all time points were averaged to obtain a single estimate for each color attribute. In general, frankfurters produced with pork fat had a darker, redder internal color when compared to other treatments, and there were some differences in

Table 5

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>mg/100 g frankfurter</th>
<th>% of fatty acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF SBO</td>
<td>10 RBW 2.5 RBW RBW/LS S.E.M.</td>
<td>PF SBO 10 RBW 2.5 RBW RBW/LS S.E.M.</td>
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<tr>
<td>Lauric</td>
<td>20.6 2.7 3.2 2.8 2.6</td>
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<tr>
<td>Tridecanoic</td>
<td>7.9 7.9 8.4 8.0 6.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Myristic</td>
<td>303.9 56.4 62.9 55.3 48.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Pentadecanoic</td>
<td>15.0 3.1 3.4 3.2 0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Palmitic</td>
<td>4209.9 2312.7 2301.4 2346.5 2197.1</td>
<td>66.4</td>
</tr>
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<td>Palmitoleic</td>
<td>545.5 57.9 65.7 63.4 64.2</td>
<td>8.3</td>
</tr>
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<td>Margaric</td>
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<td>6.7</td>
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<td>1.0</td>
</tr>
<tr>
<td>Stearic</td>
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<td>30.8</td>
</tr>
<tr>
<td>Oleic</td>
<td>7830.5 4515.7 4506.2 4735.7 4646.2</td>
<td>115.7</td>
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<td>Ascleic</td>
<td>8181c11 6.1</td>
<td>0.0</td>
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<tr>
<td>Linoeleic</td>
<td>18266 3915.2 10130.6 9898.7 10176.6</td>
<td>9374.9</td>
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<td>γ-Linolenic</td>
<td>183n6 9.06 24.0 31.0 34.6 29.8</td>
<td>2.8</td>
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<tr>
<td>α-Linolenic</td>
<td>183n3 165.1 1577.3 1498.2 1467.6 1371.0</td>
<td>66.2</td>
</tr>
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<td>Eicosanoic</td>
<td>20 35.6</td>
<td>54.6</td>
</tr>
<tr>
<td>Gadalenoic</td>
<td>201e9 167.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Eicosadenoic</td>
<td>2026n 160.9</td>
<td>16.8</td>
</tr>
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<td>Eicosatrienoic</td>
<td>203n3 19.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Dihomo-γ-linolenic</td>
<td>203n6 27.3</td>
<td>6.2</td>
</tr>
<tr>
<td>Mead</td>
<td>203n9 6.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Behenic</td>
<td>220 4.7</td>
<td>57.5</td>
</tr>
<tr>
<td>Erucic</td>
<td>221c13 64.8</td>
<td>67.6</td>
</tr>
<tr>
<td>Docosapentaenoic</td>
<td>225n3 12.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Docosahexaenoic</td>
<td>226n3 0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Lignoerice</td>
<td>240</td>
<td>2.1</td>
</tr>
<tr>
<td>Iodine value</td>
<td>g/100 g</td>
<td>70.24</td>
</tr>
<tr>
<td>n-6:n-3 FA ratio</td>
<td>22.85</td>
<td>6.48</td>
</tr>
</tbody>
</table>

S.E.M.: standard error of mean.

1 Calculated based on actual lipid content of each treatment (Table 4).
2 Calculated as IV = (% 16:1 × 0.950) + (% 18:1 × 0.860) + (% 18:2 × 1.732) + (% 18:3 × 2.616) + (% 20:1 × 0.785) + (% 22:1 × 0.723). AOCS (2017).

Table 6

<table>
<thead>
<tr>
<th>Internal color</th>
<th>Sensory color</th>
</tr>
</thead>
<tbody>
<tr>
<td>L* a* b* Darkness-internal</td>
<td>Pinkness-internal</td>
</tr>
<tr>
<td>PF 74.38a 7.81b 13.27ab 12.3a 12.6ab 12.5ab</td>
<td>0.08 0.20 0.08 0.7 1.0 0.7</td>
</tr>
<tr>
<td>SBO 78.73ab 6.51b 12.95b 5.8a 6.3a 7.6a</td>
<td>0.08 0.20 0.08 0.7 1.0 0.7</td>
</tr>
<tr>
<td>2.5 RBW 79.84c 6.08c 13.00b 4.0a 4.5a 5.7a</td>
<td>0.08 0.20 0.08 0.7 1.0 0.7</td>
</tr>
<tr>
<td>10 RBW 78.86c 6.24ab 13.31ab 5.9c 5.9c 6.0c</td>
<td>0.08 0.20 0.08 0.7 1.0 0.7</td>
</tr>
<tr>
<td>RBW/LS 77.39ab 6.73c 13.49b 7.4ab 7.8ab 7.8ab</td>
<td>0.08 0.20 0.08 0.7 1.0 0.7</td>
</tr>
</tbody>
</table>

S.E.M.: standard error of mean.

**Different superscripts within columns indicate significant differences (P < .05).**
measurements for lightness. PF was determined to be the highest in sensory darkness score and showed the lowest L* value. PF also had one of the highest internal sensory pinkness scores, and it also had the greatest a* value. Panagiotopoulou et al. (2016) reported that untrained consumer panelists noted a decrease in color acceptability for frankfurters produced with oleogels.

### 3.3 Instrumental texture

#### 3.3.1 Incisor puncture probe

Incisor puncture probe results are shown in Fig. 1. There were no significant differences in time or treatment × time interaction for incisor puncture probe; therefore, the data from all time points were averaged to obtain a single estimate for incisor puncture probe values. It took more force to puncture frankfurters which utilized soybean oil or oleogels. PF had the smallest incisor peak force (P < .05), 9.57 N, and required approximately 30% less force than SBO, 2.5 RBW, and 10 RBW which required 12.27 N, 12.31 N, and 11.88 N of force, respectively. RBW/LS had an intermediate incisor peak force (11.07 N) which was not significantly different (P = .0518) than that of all other treatments.

Incisor force area followed a similar pattern to the incisor peak force values (Fig. 1). PF had significantly less incisor force area, 12.49 N/s (P < .05), than the treatments that replaced pork fat: 19.36 N/s for SBO, 19.05 N/s for 2.5 RBW, 17.57 N/s for 10 RBW, and 17.10 N/s for RBW/LS. The lower force required to puncture through PF could be partly explained by the fact that it had a greater amount of large fat globules than all other treatments. Incisor force values are a function of the strength of the skin and how readily the internal cooked meat batter yields to force. Another texture measurement that is also a function of these two parameters is shear force. Barbut et al. (2016b) showed the greatest amount of force was necessary to shear frankfurters made with canola oil, which required more force than either beef fat or ethylcellulose oleogels, but ethylcellulose oleogel frankfurters still required more force than beef fat, even when only 20% of the beef fat was replaced with the oleogel. Barbut et al. (2016a) showed shear force was the greatest in beef frankfurters that utilized canola oil as a fat replacement, and there was no significant difference in shear force values for frankfurters that used beef fat and those that used oleogels produced with >10% ethylcellulose. This could be due to the strength of the oleogel and its ability to remain intact throughout frankfurter processing which would result in larger fat globules.

#### 3.3.2 Texture profile analysis

TPA results are shown in Table 7. There were no differences in time or a treatment × time interaction for TPA attributes, therefore, the data from all time points were averaged to obtain a single estimate for TPA characteristics. PF, 2.5 RBW, 10 RBW, and RBW/LS were all similar in firmness, whereas SBO was not as firm as PF. PF and 10 RBW were both significantly (P < .05) firmer than SBO. This is in accordance with other studies where stated firmness was found to be similar in frankfurters that had pork fat partially replaced with phytosterol oleogels (Panagiotopoulou et al., 2016). Morais et al. (2013) reported a higher TPA initial compression force on a room-temperature finely-summered meat product that replaced pork fat with vegetable oil. These studies and the present study contradict other studies that found frankfurters made with vegetable oils to be firmer than those made with animal fats (Barbut et al., 2016a; Barbut et al., 2016b; Youssef & Barbut, 2009). Oil-in-water emulsions used to replace animal fats in frankfurters have also resulted in firmer frankfurters (Carmona, Ruiz-Capillas, Jimenez-Colmenero, Pintado, & Herrero, 2011; Delgado-Pando, Cofrades, Ruiz-Capillas, & Jimenez-Colmenero, 2010; Jimenez-Colmenero, Herrero, Pintado, Solas, & Ruiz-Capillas, 2010). This could be the result of different preparation methods; for instance, Barbut et al. (2016b) used samples produced from frankfurter batter cooked in propylene tubes to do TPA; whereas the samples in the present study were analyzed as skin-on frankfurters at room temperature.

PF was significantly more adhesive (P < .05) than 2.5 RBW and 10 RBW. SBO and RBW/LS showed the same adhesiveness as PF. Adhesiveness is the stickiness of a substance to other surfaces, and the increased adhesion of frankfurters in the TPA results could be a function of the cut edge resulting in voids or pockets where the fat globules were, and the compression of the probe turning these voids into a vacuum environment, causing the sample to adhere to the probe. This hypothesis aligns with the percent area of visible fat in the microstructure data (Table 8), which showed PF, SBO, and RBW/LS as having the most area of fat globules and voids. Adhesiveness is not often reported in the literature, but Morais et al. (2013) found that adhesiveness of mortadella sausage made with soybean oil was decreased.

There were significant differences in resilience (P < .05) (Table 7). Resilience is a measure of the force exerted by the sample as it tries to regain its original shape. PF showed the highest resilience, followed by SBO, 2.5 RBW, RBW/LS, then 10 RBW. This may be because oleogels are more plastic in their nature and, as such, may be disrupted more during the primary stroke of the TPA, unlike pork fat which is more elastic, and will more readily return to its original shape once compressed. Panagiotopoulou et al. (2016) used phytosterol oleogels as a pork fat replacement as a means to improve fatty acid profile in frankfurters, and they showed resilience was not impacted by the substitution, but that study only replaced 20% of the pork fat, while in this study, frankfurters were almost entirely devoid of animal fat.

There were no differences in cohesiveness of the samples, with the exception of 10IRBW, which was significantly less cohesive (P < .05) than PF. Cohesiveness is the ratio of the force of the second compression to the force of the first compression. The higher firmness of 10 RBW, coupled with the disruption of the gel in the frankfurter which weakens the frankfurter for the second compression, could have accounted for
Fat globule size and distribution of frankfurters made with pork fat (PF), soybean oil (SBO), 2.5% rice bran wax oleogel (2.5RBW), 10% rice bran wax oleogel (10 RBW), and 2.5% rice bran wax oleogel with less shear during frankfurter preparation (RBW/LS).

Table 7
Means for effect of treatment on texture profile analysis parameters of frankfurters.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Firmness (N)</th>
<th>Adhesiveness (N/s)</th>
<th>Resilience (%)</th>
<th>Cohesiveness (%)</th>
<th>Chewiness</th>
<th>Springiness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF</td>
<td>69.62&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>–0.220&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>39.73&lt;sup&gt;c&lt;/sup&gt;</td>
<td>72.79&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4908&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>94.94&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>SBO</td>
<td>62.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>–0.145&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>39.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>74.08&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4510&lt;sup&gt;a&lt;/sup&gt;</td>
<td>96.08&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2.5 RBW</td>
<td>67.60&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>–0.101&lt;sup&gt;c&lt;/sup&gt;</td>
<td>38.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>73.00&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4789&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>95.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>10 RBW</td>
<td>75.02&lt;sup&gt;c&lt;/sup&gt;</td>
<td>–0.101&lt;sup&gt;c&lt;/sup&gt;</td>
<td>35.56&lt;sup&gt;c&lt;/sup&gt;</td>
<td>70.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5076&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94.16&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>RBW/LS</td>
<td>64.89&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>–0.184&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.25&lt;sup&gt;b&lt;/sup&gt;</td>
<td>72.46&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4541&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94.75&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>S.E.M.</td>
<td>1.44</td>
<td>0.021</td>
<td>0.13</td>
<td>0.27</td>
<td>109</td>
<td>0.17</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Different superscripts within columns indicate significant difference (P < .05).
S.E.M.: standard error of mean.

Table 8
Fat globule size and distribution of frankfurters made with pork fat (PF), soybean oil (SBO), 2.5% rice bran wax oleogel (2.5RBW), 10% rice bran wax oleogel (10 RBW), and 2.5% rice bran wax oleogel with less shear during frankfurter preparation (RBW/LS).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average number of fat globules per field</th>
<th>Fat globule average size (μm&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>Number of fat globules larger than 100 μm&lt;sup&gt;2&lt;/sup&gt; (%)</th>
<th>Fat globules larger than 100 μm&lt;sup&gt;2&lt;/sup&gt; (%)</th>
<th>Area of visible fat in the field (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF</td>
<td>62.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1467.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>49.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.46&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>SBO</td>
<td>536.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>113.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>149.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.04&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>2.5 RBW</td>
<td>106.0&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>193.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>36.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.65&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>10 RBW</td>
<td>87.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>559.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>46.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>53.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.88&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>RBW/LS</td>
<td>338.0&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>216.0&lt;sup&gt;d&lt;/sup&gt;</td>
<td>103.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.34&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>S.E.M.</td>
<td>72.3</td>
<td>324.4</td>
<td>20.8</td>
<td>5.7</td>
<td>2.47</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Different letters within columns indicate significant difference (P < .05).
S.E.M.: standard error of mean.

The decrease of cohesiveness for 10 RBW. Panagiotopoulou et al. (2016) did not find a difference in cohesiveness among frankfurters when 20% of pork fat was replaced with oleogels. Oil-in-water emulsions have been shown to not influence cohesiveness in frankfurters (Delgado-Pando et al., 2016; Cofrades, Antonio, Solas, Herrera, & Jiménez-Colmenero, 2013), but others have shown oil-in-water emulsions to decrease cohesiveness in frankfurters (Jiménez-Colmenero et al., 2010).

For chewiness, all treatments were similar to the PF control (Table 7). This agrees with Zetzl et al. (2012), Delgado-Pando et al. (2016), and Cofrades et al. (2013), who reported that animal fat replacement with oleogels or oil-in-water emulsion strategies can effectively reproduce the chewiness of animal fat frankfurters. However, changes in chewiness from the control was a concern in the present study because some literature found oil and oil-in-water emulsion replacements in frankfurters to increase chewiness (Barbut et al., 2016a; Barbut et al., 2016b; Jiménez-Colmenero et al., 2010). Additionally, the 10 RBW treatment had significantly (P < .05) higher chewiness values than SBO and RBW/LS.

Oleogels are effective at mimicking the springiness of the PF control (Table 7). PF was not significantly different from 2.5 RBW, 10 RBW, or RBW/LS. However, PF and the oleogel treatments were significantly less springy (P < .05) than SBO. This increase in springiness of frankfurters made with vegetable oil has been previously noted (Youssef & Barbut, 2010).

3.4. Lipid oxidation

Lipid oxidation remained steady over time for all treatments (Fig. 2). This can be expected because of the antioxidant activity of sodium nitrite. Lipid oxidation values for PF, SBO, and 2.5 RBW did not differ significantly from each other. Additionally, RBW/LS had similar lipid oxidation values as PF at each of the timepoints, with the exception of day 42 (P < .05). The 10 RBW treatment had significantly greater (P < .05) TBA values than PF at every treatment point. This could indicate the 10% rice bran wax oleogel had more lipid oxidation than pork fat before it was incorporated into the frankfurters, and that the lipid oxidation reaction was stifled by antioxidant ingredients once inside the frankfurters. 10 RBW also had significantly (P < .05) greater TBA values than SBO on days 0, 42, 70, and 84. Since exposure to heat can accelerate lipid oxidation, this could have resulted from the longer heating time required to dissolve the wax in the oil when making the 10% RBW oleogels. Despite these differences, lipid oxidation does not seem to be of much concern in cured products that use oils or oleogels since TBA values never exceeded 0.201 mg/kg for any treatments at any time, and sensory panelists did not detect any off-flavors. However, more research should examine fresh meat products that utilize oleogels, as they do not have the advantage of cure as an antioxidant.

Our results are in agreement with Álvarez et al. (2011) who found similar TBA values for frankfurters produced with pork backfat (0.160 mg/kg) and those produced with canola oil (0.168 mg/kg). Choi et al. (2010) found that different oils increase oxidation levels of frankfurters. Soybean oil was more prone to oxidation than pork backfat, olive oil, grape seed oil, corn oil, and canola oil in frankfurters.

3.5. Sensory analysis

Although cured frankfurter aroma was the same for all treatments, cured frankfurter flavor was significantly reduced (P < .05) when pork fat was replaced (Fig. 3). Saltiness perception was significantly lower (P < .05) for SBO as compared to PF, despite all treatments being formulated with the same salt content, but there were no other...
There were no significant increases in off-flavors as a result of pork fat replacement, but there was a tendency \((P = .0935)\) for 10% RBW to be greater in off flavors than PF. Noted flavors from the panels included “plastic” or “grassy” in this treatment, which could be flavors associated with the rice bran wax. Delgado-Pando et al. (2010), also noted that oil-based alternatives to animal fat in frankfurters did not lead to increased sensory off-flavors.

Sensory panels were able to partition frankfurters made with pork fat and those made without pork fat based on texture differences. Oleogel treatments and the soybean oil treatment were significantly \((P < .05)\) firmer and more chewy than frankfurters produced with pork fat. These results are in contradiction with the TPA results, where PF was firmer than SBO but did not differ from oleogel treatments, and there were no differences for chewiness between PF and other treatments. In both sensory analysis and TPA, product was analyzed with the skin on, along the cut surface. This could mean that TPA is not a direct relationship to what consumers perceive, or this may be impacted by the fact that TPA was performed at room temperature frankfurters, whereas sensory panelists were presented with heated product. The sensory firmness values better aligned with the values derived from using the incisor probe.

Other animal fat replacements such as oil-in-water emulsions have also shown to increase firmness of frankfurters according to sensory evaluation (Delgado-Pando et al., 2010). The data from the present study differs from Barbut et al. (2016a) and Barbut et al. (2016b), who reported frankfurters made with ethylcellulose oleogels were less firm than those containing vegetable oil, and oleogel frankfurters and beef fat frankfurters were similar in firmness. In those studies, oleogel substitution never exceeded 80% of the lipid portion of the frankfurter, whereas the present study replaced essentially all of the animal fat. Additionally, those studies were carried out with beef frankfurters made with ethylcellulose oleogels. The present study also differs from Barbut, Wood, and Marangoni (2016c), who showed that ethylcellulose oleogel resulted in decreased firmness in breakfast sausages where up to 70% of the animal fat was replaced with ethylcellulose oleogels.
according to trained sensory panelists. Panelists’ training and different processing may have accounted for some discrepancies. In the present study, no differences in mouth-coating were detected between treatments.

3.6. Microstructure

Samples of microstructure images are shown in Fig. 4, and image analysis data are shown in Table 8. Microstructure analysis revealed that the PF control had the largest fat globules \((P < .05)\). PF and 10 RBW had a larger proportion of their fat globules \(> 100\,\mu m^2\) in area \((P < .05)\), 49.9% and 53.3%, respectively. This may indicate that increasing the level of rice bran wax gelator in the oleogel resulted in a stronger oleogel which could better withstand shear during the frankfurter preparation.

Microscopically, oleogel treatments appeared to have fewer visible fat globules than PF or SBO (Fig. 4). Image analysis software revealed that in PF 14.46% of the area of the image consisted of lipid, which was significantly more \((P < .05)\) than 2.5 RBW and 10 RBW in which 2.65% and 6.88% of the area, respectively, were visible lipid. However, PF did not differ from SBO or RBW/LS, which could indicate that either the oleogels broke into pieces that were too small for the image analysis software to detect, or that the oleogel dissolved into the protein phase of the emulsion perhaps due to the hydrophilic properties of some of the minor constituents of rice bran wax. Reducing shear, as was the case with the RBW/LS treatment, may help keep the oleogel more intact and prevent it from associating with the hydrophilic protein phase. Barbut et al. (2016a) also presented micrographs which showed beef fat frankfurters to have noticeably larger fat globules than frankfurters made with native canola oil, and the micrographs of frankfurters
produced with ethylcellulose oleogels appeared similar more to the beef fat frankfurters.

4. Conclusions

This study demonstrates the potential of oleogel technology to provide an alternative to animal fat in processed meat products. Oleogels and soybean oil as a fat substitute resulted in frankfurters with acceptable technological quality, as indicated by emulsion stability and cook/chill yields similar to those of the pork fat control. Furthermore, lipid oxidation for all treatments, although higher in 10 RBW, was maintained below the sensory threshold. Although oleogel treatments were unable to fully match the texture of frankfurters made with pork fat, as indicated by the sensory evaluation scores and the incisor probe analysis, even the weakest oleogel matched TPA firmness and springiness of pork fat frankfurters, something that soybean oil by itself could not do. Moreover, all treatments maintained steady texture attributes throughout shelf-life, indicating that the oleogels within the frankfurters retained their structure for the entirety of the 98-day shelf-life of the study. TPA also revealed that oleogels and soybean oil were able to match pork fat in adhesiveness, cohesiveness, and chewiness. Both sensory evaluation scores and instrumental color measurement showed that pork fat frankfurters were darker and redder, but consumer acceptance testing is necessary to determine if these differences are of practical significance and whether they would affect consumer preference. Microstructure data indicated that using a stronger oleogel with a higher inclusion of gelator may be necessary to withstand processing conditions, and future research should examine the influence that variations in meat processing procedures may have on the texture attributes of these products. As shown by the RBW/LS treatment in the microstructure data, treating these gels as one would adipose tissue may not be the best approach to simulate the microstructure and, subsequently, the texture of traditional products made with animal fat.

While our results indicate that rice bran wax/soybean oil oleogels can produce acceptable comminuted meat products, the color measurements and sensory evaluation of flavor and texture indicate that the performance of oleogels is more like that of native soybean oil. This could be achieved by using the high-quality raw materials used in the product formulation and suggests that these oleogel systems should be tested in similar products that utilize lower-quality raw materials (e.g., mechanically separated poultry) as sources of lean meat protein and that are formulated to lower protein contents, such as commonly seen in commerce. On the other hand, in coarsely-ground products where the lipid and lean phases must be discernible in the final product, the fat-like appearance of oleogels may make them more desirable than native oil as an animal fat alternative. This study showed the ability of rice bran wax oleogels to withstand high-shear processing, maintain technological quality, and remain beneath an acceptable lipid oxidation threshold. Future studies on comminuted products should focus on formulations that contain less protein and utilize less functional meat raw materials, such as mechanically separated poultry, as is common in the meat industry. Coarsely-ground products, both fresh and fully-cooked, may benefit from this animal fat alternative, provided a way to improve the hardness of the oleogels can be found. The potential of oleogels as a delivery mechanism for liposoluble nutritional components in meat products is another promising application area for this technology. It is noteworthy that at current raw material and ingredient market prices, soybean oil/rice bran wax oleogels are higher cost options than animal fats; therefore, they must deliver benefits for which consumers are willing to pay a higher price.

Future research should look at the effects of oleogels in coarsely-comminuted meat products, both fully-cooked and fresh, as these products could also gain consumer appeal from improved fatty acid profiles and health benefits.

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