Vegetable organogels incorporation in cream cheese products

Hanna L. Bemer, Melissa Limbaugh, Erica D. Cramer, W. James Harper, Farnaz Maleky *

Department of Food Science and Technology, The Ohio State University, 2015 Fyffe Ct., Columbus, OH 43210, United States

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ABSTRACT

Edible oleogels made from rice bran wax (RBW) or ethylcellulose (EC) organogelators in combination with vegetable oils and other non-fat ingredients were used to produce oleogel cream cheese products. Four oleogel cream cheese products, two containing RBW and two with EC, were prepared and compared to control samples including full-fat and fat-free commercial cream cheese samples. Upon compositional analysis, all the oleogel cream cheese (OCC) samples showed approximately a 25% reduction in total fat content in comparison to the full-fat commercial control. More specifically by the replacement of saturated fat with healthier unsaturated fat alternatives, an improved fatty acid profile of cream cheese products was documented. Similar compositional analysis was also performed on a cream cheese sample made with non-gelled vegetable oil. Using a single penetration test and a strain sweep test, oleogel cream cheese samples prepared with RBW displayed comparable hardness, spreadability, and stickiness values to the full-fat commercial control sample. EC OCC samples also showed comparable hardness, spreadability and stickiness values but exhibited reduced adhesiveness values compared to the full-fat control. The successful microstructural incorporation of oleogels into a cream cheese, along with similarities in fat globule size, between OCC samples and commercial controls was confirmed with Confocal Laser Scanning Microscopy. The similarity in microstructure can be accounted for the similarities in textural properties between the OCC samples and the full-fat control. These results provide a thorough characterization of the use of RBW and EC in oleogels and their potential as a healthy alternative to saturated fat in cream cheese applications.

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1. Introduction

The demand for low-fat and fat-free food products has become more than just a trend ever since these products were introduced in U.S. markets. Consumers have become increasingly aware of the association between the etiology of certain chronic diseases (obesity, cardiovascular disease, and cancer) depending on the amount and type of fat consumed (Romeih, Michaelidou, Biladeris, & Zerflidis, 2002). Although the harmful effects of some saturated fats are in debate, numerous studies have confirmed that it is best to minimize the daily intake of saturated fats food (Mensink, Zock, Kester, & Katan, 2003). Conversely, poly and mono unsaturated fats (PUFAS and MUFAS) have been shown to increase high-density lipoprotein (HDL) ("good cholesterol") levels and decrease low-density lipoprotein (LDL) ("bad cholesterol") levels and are therefore thought to decrease the risk of contracting heart disease (Mensink et al., 2003; Roche, 2005). This association has been the driving force behind the expansion of low-fat and low saturated-fat dairy products.

However the removal of fat and changing fat type, remains a challenge since it adversely affects the flavor, texture, and appearance of low-fat products (He, Xue Ming, & Shi Dong, 2008). For example, reduced fat cheeses are reported to be firm and less elastic compared to their full-fat counterparts (Emmons, Kalab, & Larmond, 1980). In addition, low fat cheeses are characterized by rubbery texture, off-flavor, poor meltability, and undesirable color (Lashkari, Khosrowshahi, Madadlou, & Alizadeh, 2014).

Fat replacers, often carbohydrate-based compounds, are frequently used to replace natural fats in cheese with the objective of reducing the caloric value (Romeih et al., 2002). While using fat replacers such as pectin gels and gums can be an effective way to create a low-fat cheese product, there are problems that arise in the formulation of these products. On the other hand, direct substitution of saturated fats with liquid oils composed of MUFAS and PUFAS does not lead to food products with comparable textural attributes (Youssef & Barbut, 2009; Zetzl, Marangoni, & Barbut, 2012) because saturated fats are typically responsible for creating desirable rheological properties and mouthfeel in various foods such as dairy and meat products.

One of the most recent oil structuring techniques being explored involves the use of edible organogels in structuring liquid oils (Co & Marangoni, 2012; Zetzl et al., 2012). Organogelators such as wax esters, monoacylglycerols (MAGS), 12-hydroxyoctaeic acid (12-HSA), are used in place of the traditional triacylglycerol crystalline fat networks, to create a 3-D gel-like substance (Marangoni & Garti, 2011; Rogers, Wright, & Marangoni, 2008; Zetzl & Marangoni, 2011).

* Corresponding author.
E-mail address: Maleky.1@osu.edu (F. Maleky).
A limited number of studies have structured vegetable oils (composed of PUFA and MUFA) with different edible organogels and incorporated these gels into food systems (Patel et al., 2014; Stortz & Marangoni, 2013; Zetzl et al., 2012; Zulim Botega, Marangoni, Smith, & Goff, 2013). These works have evaluated the rheological characteristics of edible oleogels matrices under a variety of conditions and found them to be a potential replacement for saturated fatty acids in food systems (Co & Marangoni, 2012). Zulim Botega et al. (2013) reported that RBW oleogel was effectively emulsified into low saturated fat ice cream mix and led to the formation of small fat droplets and gelled droplets. The level of fat destabilization between the RBW oleogel ice creams and milk fat controls were comparable (Zulim Botega et al., 2013). In another study, when EC was used in the formulation of canola oil organogel to replace saturated fat in frankfurters, the organogel produced a product that was not statistically different in either hardness or chewiness when compared to the hot dogs made with beef fat (Zetzl et al., 2012).

An investigation was conducted into the use of shellac oleogels as a replacer for oil binder in chocolate paste as well as a structurant alternative to shortening in cake formulation (Patel et al., 2014). Chocolate paste made with shellac oleogel was stored at 30 °C and showed no signs of "oiling out" even after 4 weeks, suggesting that the replacement oil binder with the oleogel did not have any effect on the physical stability of the paste (Patel et al., 2014). Cakes also prepared with shellac oleogel had comparable firmness and cohesiveness values to cakes made with margarine (Patel et al., 2014).

The recent developments of oleogel food products encouraged us to further investigate their usage in other food products such as cream cheese. The objective of this study was to incorporate an oleogel, initially combined with skim milk, into a cream cheese product using edible oleogels, made from rice bran wax (RBW) or ethylcellulose (EC) and liquid vegetable oils. Rheological and textural properties of the oleogel cheese product were evaluated and compared to different commercial cream cheese products.

2. Materials and methods

2.1. Materials

Skim milk, soybean oil, salt, and non-fat dry milk (NFDM) were purchased from a retail food market. High-oleic soybean oil (HO SO) was acquired from Bunge (St. Louis, MO). Ethylcellulose (EC) and rice bran wax (RBW) were provided by Dow Chemical Company (Hebron, OH) and Koster Keuten (Watertown, CT), respectively. Whey protein isolates (WPI) and starter cultures containing rennet were obtained from Hilmar Cheese Company (Hilmar, CA) and Cultures for Health (Sioux Falls, SD), respectively. All gums were kindly provided by TIC gums (White Marsh, MD). Fast green FCF and Nile red were acquired from Fisher Scientific (Waltham, MA, BP123-10), and Sigma- Aldrich (St. Louis, MO), respectively. Two commercial cream cheese spread samples, original (full-fat) and fat free cream cheese, were purchased from local grocery stores.

2.2. Processing techniques for preparation of oleogel cream cheese products

Four oleogel cream cheese (OCC) samples labeled as EC1, EC2, RBW1, and RBW2 were prepared and analyzed in this study. Ethylcellulose (EC, 45 cP) was used as the structuring agent for high-oleic soybean oil and regular soybean oil to prepare samples EC1 and EC2, respectively. Following the method described by Zetzl and Marangoni (2011), a 10:90 w/w mixture of ethylcellulose and vegetable oil was made and heated to 25 °C/min above the glass transition temperature (130 °C for EC). The samples were cooled from 130 °C to 75 °C at 10 °C/min. Once the gel had formed upon cooling to 75 °C, the heated skim milk, whey protein isolate (0.5% and 2% w/w), and non-fat dry milk (8 and 10% w/w) were added. The mixture was blended using a two-speed Waring Laboratory Blender (Waring Pro Products, Odessa, FL) on the “high” setting. Samples were cooled to 30 °C and about 1.5% w/w Lactococcus lactis subsp. Lactis, L. lactis subsp. Cremoris culture and rennet were added. Samples were then allowed to coagulate for approximately 14–16 h, followed by a 12 hour-long whey drain. Both coagulation and whey drain occurred at 22 °C. Samples were then refrigerated at 4 °C for 12 h and salt (0.2 and 0.5% w/w), gums (0.5% w/w) (xanthan and guar), were then added to the products. All the oleogel cream cheese samples were prepared in triplicate and transferred for further analysis. Using rice bran wax as the oil structuring agent instead of ethylcellulose, samples RBW1 & RBW2 were prepared in a similar manner, with a few minor differences. Rice bran wax was combined with vegetable oil and heated above the melting point of rice bran wax (85 °C) with moderate mixing at 300 RPM. The main differences between samples RBW1 and RBW2 is that RBW1 contains 10% (w/w) NFDM while RBW2 contains only 8% (w/w) NFDM. The remainder of the procedure for samples EC1 and EC2 is identical to that illustrated above.

Two commercial cream cheese spreads including a full-fat and a fat-free cream cheese spread (labeled as P1 and P2, respectively) were utilized as control samples. Moreover, a third control sample (named as P3) was also prepared using non-gelled vegetable oil in place of oleogelled oils. For the non-gelled control 10% of high-oleic soybean oil was combined with 79% (w/w) skim milk and heated to 85 °C at a rate of 25 °C/min with moderate shearing (300 RPM). Once the sample was heated, 1% (w/w) of whey protein isolates and 10% (w/w) of non-fat dry milk were added to the solution and blended on “high” setting. The remainder of the processing for the non-gelled sample was similar to the procedure described in oleogel cheese samples.

2.3. Analysis of cream cheese samples composition

Analysis of cream cheese samples’ composition, including moisture, total non-fat solids, and fat, were conducted with a CEM Smart Tric II machine (CEM Corporation, Matthews, NC). The samples were analyzed in triplicate as described by the Association of Analytical Communities (AOAC) method for dairy products (Cartwright, McManus, Leffler, & Moser, 2005). This method involves placing a CEM sample pad on the balance component within the “CEM Smart System.” 2.2–2.5 g of samples were spread and covered between two sample pads. “CEM Smart System” was used to dry the sample (Cartwright et al., 2005). The dried sample was folded and rolled into a CEM "trac tube," placed in the “Smart Trac” system. The “Smart Trac” system used Low-Resolution Time Domain Magnetic Resonance (LR-NMR) to evaluate the “transverse relaxation” of the lipid protons, thus yielding the sample fat content (Cartwright et al., 2005).

To determine if syneresis had occurred, the moisture content of RBW1 and RBW2 samples were measured over Days 1, 2, 3, 7 and 10 using the method described above.

2.3.1. pH measurements of the cream cheese samples

Using an Accumet pH meter 25 (Fisher Scientific, Waltham, MA) all the samples pH values were measured.

2.4. Confocal laser scanning microscopy

Olympus FV 1000 Spectral Confocal microscope system (Olympus Corporation, Tokyo, Japan) was utilized with a 40 × oil-immersion objective to image the microstructure of the samples. Nile Red (prepared as a 0.02 g/L solution in acetone) and Fast Green FCF (prepared as a 0.1 g/L solution in distilled water) was used to dye the lipid components and the protein content of the samples, respectively (Gallier, Gragson, Jiménez-Flores, & Everett, 2010). 10 μL of each dye solution was mixed with 25 mg of the cheese products and stored at 4 °C for 24 h. The mixture was then spread evenly on a super frost, pre-cleaned slide and covered with a cover glass (22 × 22) (Fisher Scientific, Pittsburgh, PA). Two
laser beams, including a helium-neon laser and an argon laser with excitations at 543 nm and 633 nm, were utilized in this study. The emission wavelength was set at 572 nm for Nile Red and 647 nm for Fast Green. At least three optical sections were taken for each sample, and microstructure images (sized 512 × 512 pixels with a 2 × zoom factor) were obtained. Fiji software, a form of ImageJ (Research Services Branch, National Institute of Health, Bethesda, MD) was used to measure the area of the fat globules in the micrographs.

2.5. Texture analysis

Using a TA-XT2 texture analyzer machine (Texture Technologies Corporation, Scarsdale, NY), a single penetration test was performed to determine the textural properties of cream cheese samples. The machine was equipped with a 5-kg load cell and testing was performed at 4 °C. Samples were filled to the top of 0.75 oz. plastic cups, smoothed with a metal spatula, and refrigerated for approximately 24 h prior to measurement. A 30-degree perpex cone penetrated the sample to 40% of its depth. A representative of the typical curve obtained from the single penetration test is shown in Fig. 1 (Bayarri, Carbonell, & Costell, 2012). All the samples were analyzed for their spreadability, hardness, stickiness, and adhesiveness as described by Bayarri et al. (2012). These four textural properties were calculated using the macro function on Texture Expert Exceed software (Texture Technologies Corporation, Scarsdale, NY, version 2.64). As demonstrated in Fig. 1, the positive (A1) and the negative area (A2) correspond to spreadability and adhesiveness. Hardness and stickiness were calculated by the peak positive force (F1) and the peak negative force (F2), respectively.

2.6. Samples’ storage modulus measurements through a strain sweep test

Dynamic small-amplitude oscillatory rheology was conducted utilizing a controlled-strain modular compact rheometer equipped with a temperature controlled peltier base plate (Anton Paar MCR 302 Rheometer, Ashland, VA). A strain sweep test was conducted from 0.01% to 100% strain with frequency and temperature values at 1 Hz and 25 °C, respectively. Approximately 5 g of the samples were placed on the base plate (as described above) until the pre-determined gap size (2 mm) was reached. G′, also known as the storage modulus (or elastic modulus), is a measure of the energy stored and recovered per oscillation (Tunick, 2011). G′ values were measured in quadruplicate.

2.6.1. Samples’ storage modulus measurements through a temperature sweep test

To evaluate the rheological behavior of the samples under a range of temperatures, a temperature sweep test was also conducted. Cream cheese samples were placed on the base plate (as described above) and were heated from 5 °C to 80 °C at a continuous rate of 5 °C/minute. The strain value of 0.1% and a frequency of 1 Hz were used. Samples’ G′ values and their dependency on temperature were evaluated.

2.7. Gas chromatography – Preparation of fatty acid methyl esters

Fatty acid methyl ester (FAME) gas chromatography was used to evaluate the fatty acid profiles of the soybean, and high-oleic soybean oils utilized in this study (David, Sandrã, & Vickers, 2005). 100 μL of each vegetable oil was dissolved in 10 mL of hexane (Fisher Scientific, Waltham, MA) and placed in a test tube (25 mm × 150 mm). After adding 100 μL of 2 N potassium hydroxide in methanol (Fisher Scientific, Waltham, MA) to the solution, 1.5 mL of the vortexed sample was placed into a centrifuge tube and approximately 0.5 g of sodium sulfate anhydrous was added to the sample. The prepared supernatant was centrifuged at 13.2 rpm for 10 min at 24 °C and transferred into a 2 mL vial. Fatty acid methyl esters were analyzed using a Hewlett Packard 6890 Gas Chromatograph equipped with a flame ionization detector (FID) and an HP G1513A auto-sampler (Agilent Technologies, Santa Clara, CA, USA). Separation of the fatty acid methyl esters was conducted using an HP-88 60 m × 0.25 mm × 0.2 μm column (Agilent Technologies, Santa Clara, CA, USA) with helium as the carrier gas. The injection volume was 1.0 μL with a split ratio of 200:1. The oven conditions were adjusted for each of the measurements described above.

2.8. Statistical analysis

All data was statistically analyzed using a one-way ANOVA test performed with SPSS software (IBM, SPSS Incorporation, Chicago, IL, version 22.0). A Tukey test with a significance level of 5% was used to determine the significance of differences between mean values for each of the measurements described above.

2.9. Sensory analysis

Samples of RBW1 and full-fat commercial control cream cheese spreads were prepared in 5.5 oz. cups with spoons. Twenty test subjects were recruited from the general population through the Consumer Sensory Testing program at The Ohio State University. Each participant was

Table 1

| Fatty acid composition (percentage) of vegetable oils determined by fatty acid methyl ester (FAME) gas chromatography (each data point represents mean ± SE measured in duplicate). |
|---|---|---|
| Fatty acid Soybean High-oleic soybean |
| 16:0 | 11.5 ± 0.0 | 66 ± 0.1 |
| 18:0 | 3.0 ± 0.0 | 37 ± 0.1 |
| 18:1 | 71 ± 0.7 |
| 18:2 | 56.0 ± 0.1 | 7.1 ± 0.0 |
| 18:3 | 7.0 ± 0.0 | 1.9 ± 0.0 |
given two rounds of samples, and asked to answer questions through a computer program (Compusense v. 5.2, Guelph, ON) on each set of samples. Participants were given a 5-point Just About Right (JAR) test on certain attributes to determine if the attribute was too much (score of “5”), too little (score of “1”), or “just about right” (score of “3”). The attributes measured were hardness, spreadability, flavor, mouthfeel, sweetness, and bitterness. The data were analyzed using a computer program with a 2-sample t-test at 95% confidence.

3. Results and discussion

3.1. Cream cheese samples compositional analysis

The oleogels cream cheese samples’ (OCC) moisture content, as well as their solid, and fat content, were analyzed and compared to those of the commercial cream cheese spreads (P1 and P2) and the non-gelled control sample (P3). As shown in Table 2, the moisture contents (%) of the full-fat and fat-free commercial cream cheese samples were significantly higher than the OCC samples. Yet, no significant differences were observed between the moisture content of OCC samples prepared with RBW (RBW1 and RBW2) and EC (EC1 and EC2).

The moisture content of RBW1 and RBW2 samples on Days 1, 2, 3, 7, and 10 were measured to determine if syneresis had occurred. The moisture content values of RBW1 were consistently within 58.8–62.7% with an average of 60.3%, while RBW2 showed moisture content values that ranged from 59.4–60.1% with an average of 59.7%. Since there were no significant increases in moisture content values overtime in neither RBW1 nor RBW2, it was concluded that syneresis was not present in the OCC samples.

Data obtained for the CEM analysis was used to determine the non-fat solid content of the product based on the percentage of protein, carbohydrates, and ash (Cartwright et al., 2005). All the OCC samples showed a significantly higher solid content than the full-fat cream cheese control (P1), however, three OCC samples (Samples EC1, EC2, and RBW2) had a comparable solid content to the non-gelled control sample (P3). The discrepancy of RBW1 was related to the higher NFDM content of this sample. As reported in Table 2, all the OCC products displayed a 25% reduction in total fat content in comparison to the full-fat commercial cream cheese sample. The fatty acid profiles of the oils, shown in Table 1, were used to calculate the differences in saturated and unsaturated fats contents of the OCC samples. As anticipated, the OCC samples had over a 120% increase in unsaturated fat content and an approximate 90% reduction in saturated fat content in comparison to the full-fat control sample. These results demonstrated that replacing saturated fat with beneficial unsaturated fats in a cream cheese product was accomplished successfully.

3.2. pH measurements

pH levels of the OCC samples were within the acceptable pH range of 4.4–4.9 as described by the FDA cream cheese standards of identity (Code of Federal Regulations, 2006).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture (%)</th>
<th>Non-fat solids (%)</th>
<th>Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>65.83 ± 0.07a</td>
<td>13.81 ± 0.07a</td>
<td>20.36 ± 0.45a</td>
</tr>
<tr>
<td>P2</td>
<td>74.34 ± 0.05b</td>
<td>25.66 ± 0.05b</td>
<td>00.00 ± 0.00b</td>
</tr>
<tr>
<td>P3</td>
<td>59.77 ± 0.53c</td>
<td>22.22 ± 0.53c</td>
<td>18.01 ± 0.13c</td>
</tr>
<tr>
<td>RBW1</td>
<td>60.25 ± 0.11c</td>
<td>25.23 ± 0.33c</td>
<td>14.52 ± 0.14c</td>
</tr>
<tr>
<td>RBW2</td>
<td>6.06 ± 0.16d</td>
<td>23.29 ± 0.16d</td>
<td>15.65 ± 0.18d</td>
</tr>
<tr>
<td>EC1</td>
<td>61.94 ± 0.45c</td>
<td>22.42 ± 0.45c</td>
<td>15.65 ± 0.18c</td>
</tr>
<tr>
<td>EC2</td>
<td>62.16 ± 0.47d</td>
<td>22.67 ± 0.48d</td>
<td>15.13 ± 0.40d</td>
</tr>
</tbody>
</table>

3.3. Microstructural analysis

As detailed in the material and methods section, Confocal Laser Scanning Microscopy (CLSM) was used to study the samples microstructure and to image lipid and protein fractions of the products (Dürenberger, Handschin, Conde-Petit, & Escher, 2001). CLSM provided high-resolution imaging of cream cheese, and more specifically, allowed for the capture of multiple optical stacks of images on the z-plane, resulting in a 3-D micrograph (Dürenberger et al., 2001). CLSM micrographs of the full-fat control commercial cream cheese samples and the cream cheese samples produced with EC and RBW are shown in Fig. 2. In this study, the lipid component was stained with Nile Red and is represented in first column of this figure, and the middle column of the figure represents the protein component stained with Fast Green FCF. The third column is a superimposition of both lipid and protein components of the specimens. This figure clearly revealed a similar structural network for the commercial cream cheese samples and the oleogel cream cheese products. Both set of samples contained numerous small lipid globules dispersed throughout a continuous protein matrix and the RBW oleogel sample appeared to have a more dense protein network compared to the others. Moreover, the morphology and distribution of the fat globules appeared to be similar for both types of OCC samples (either made from EC or RBW), as well as the control specimen. In order to further evaluate these similarities between fat globules, quantitative analysis of the micrographs area size was conducted using Fiji software (Imagej). Average lipid globule areas for each cream cheese sample are displayed in Fig. 3. The average lipid globule area (microns) for the commercial full fat control was 9.52 ± 0.11 μm, the areas for the RBW oleogel sample and the EC oleogel sample were reported as 8.74 ± 0.11 μm and 8.84 ± 0.15 μm, respectively. Statistical analysis showed no statistical difference between the fat globule area of the oleogel cream cheese samples and the commercial control (p > 0.05). The results from EC samples were in agreement with data reported for frankfurters made with EC by Zetzl et al. (2012), who reported that the lipid globules in the frankfurter containing EC oleogels resembled the microstructure of the frankfurters containing animal fat. While these similarities were not observed in the non-gelled cream cheese products, one could conclude that the lipid globule size comparability between OCC and P1 samples were likely related to the gelation of the oil rather than direct fat replacement with a liquid vegetable oil.

3.4. Textural analysis

Due to the importance of the processing parameters and product formulations including, total fat content, type and amount of hydrocolloid gums, and solid content on textural properties of cheese products (Brighenti, Govindasamy-Lucey, Lim, Nelson, & Lucey, 2008; Gunasekaran & Ak, 2003; Lucey, Johnson, & Horne, 2003; Monteiro, Tavares, Kindstedt, & Gigante, 2009), samples' textural properties were assessed using single penetration tests (Fig. 4(a-d)). The relative hardness of the samples, represented by the peak force of the positive curve in Fig. 1, (Gunasekaran & Ak, 2003) is reported in Fig. 4a. All four oleogel cream cheese products, EC1, EC2, RBW1, and RBW2, showed comparable hardness values which are similar to the full-fat control samples. These results were interesting since all the oleogel cream cheese (OCC) samples had significantly lower fat contents than the control samples. Previous studies have shown that cheese hardness is significantly affected by chemical composition and more specifically by its fat content (Brighenti et al., 2008; Lucey et al., 2003). Brighenti et al. (2008) reported lower hardness values for the reduced fat cheese products. Lucey (2008) showed a significant reduction in hardness and storage modulus (G') of cream cheese products made with lower fat content. Studies also reported a firmer texture for full-fat cream cheeses (with a pH of 4.7) compared to the same cream cheeses with a pH of 5.2 and suggested that the greater degree of firmness at pH 4.7 is related to
the isoelectric point of casein at pH = 4.6 (Almena-Aliste & Kindstedt, 2005, Guinee, Pudja, & Farkye, 1993). Surprisingly, the non-gelled control (P3) demonstrated significantly higher hardness values than the full-fat commercial control and the oleogel samples. This finding supported the data published by Zetzl et al. (2012), who used edible oleogels in the production of reduced-saturated fat frankfurter. These researchers correlated the significantly greater hardness values to a stronger protein network in non-gelled canola oil products (Zetzl et al., 2012).

In order to better quantify samples’ textural attributes, all the samples’ spreadability were also measured and compared (Fig. 4b). Spreadability is defined as “the ease of spreading of a cube of cheese with a knife, lesser spreadability values indicate a greater ease of cheese spreading (Bayarri et al., 2012; Gunasekaran & Ak, 2003). As documented in Fig. 4b, all oleogel cream cheese samples made of either RBW or EC displayed similar spreadability values, which were comparable to the full-fat control cream cheese sample. The results obtained for the non-gelled sample spreadability were consistent with its hardness trend and a higher spreadability was reported for the samples made with liquid vegetable oils. Numerous studies have indicated a relationship between lipid globule sizes and the strength and meltability of the cheese (Lopez, Camier, & Gassi, 2007; Noronha, O’Riordan, & O’Sullivan, 2008). Studies have shown that smaller fat globule sizes result in firmer cheese products because a decrease in fat globule size may allow for increased interactions between proteins within the network (Noronha et al., 2008). Therefore, the similarities in textural attributes between the OCC samples and full-fat control (P1) may likely be explained by the similarities in lipid globule size, as shown in Fig. 3.

Samples’ stickiness, “the extent to which cheese sticks to the tongue and palate after normal mastication”, and adhesiveness, “force required to remove the cheese from the palate during eating” (Gunasekaran & Ak, 2003) are shown in Fig. 4c and d, respectively. As shown in Fig. 4c,
all the oleogel samples demonstrated comparable stickiness values, which are similar to those of the control samples. However, a different trend was observed for the samples' adhesiveness values. Overall, all the oleogel cream cheese samples (OCC) showed lower values for stickiness and adhesiveness compared to the control samples. While all OCC samples' adhesiveness were not significantly different (p < 0.05) from the full-fat and fat free controls, the ethylcellulose samples' values were significantly different from the full-fat control samples. Samples made with RBW were able to successfully mimic the textural profile of the full-fat cream cheese control sample at 4 °C. More specifically, RBW cream cheese samples (Samples RBW1 and RBW2) showed comparable results to the control in each of the four categories (spreadability, hardness, stickiness, and adhesiveness). However, cream cheese products made with ethylcellulose did not show the same trend for their adhesiveness. To further investigate these observations, and to establish a relationship between the networks structural properties and their mechanical properties, samples' rheological properties under small deformation were also studied.

3.5. Rheology: Strain sweep

Strain sweep tests were conducted to determine the storage modulus (G') within the linear viscoelastic region of the cream cheese samples. As reported in Fig. 5a, two OCC samples, RBW1 and RBW2, demonstrated comparable G' values to the full-fat control. When other studies linked the similarities in storage modulus values to the comparable liquid globule size of the samples (Fig. 3) (Noronha et al., 2008; Zetzl et al., 2012), it is important to consider the effects of other
structural properties including particle size and distribution on rheological properties as well. This principle was evident when comparing the $G'$ values between EC and RBW samples. OCC samples made with ethylcellulose (EC1 and EC2) showed significantly lower $G'$ values compared to the full fat control and RBW samples, regardless of their similarity in particle size. The discrepancy between the EC samples and the RBW samples were not unexpected as the EC samples displayed significantly lower adhesiveness values as well. In addition to the microstructural and nanostructural properties on the final rheological characteristics, studies have shown different mechanical properties for oleogel systems made by different organogelators. Previous rheological studies utilizing wax ester oleogels indicated that organogelator type, along with molecular weight and concentrations, were positively correlated with storage modulus ($G'$) values of the structured networks (Co & Marangoni, 2012; Morales-Rueda, Dibildox-Alvarado, Charó-Alonso, & Toro-Vazquez, 2009). Similar to the values reported for the large deformation analysis, the non-gelled control (P3) showed significantly higher $G'$ values. The results from this study reflected those illustrated in Zetzl et al. (2012), who found that frankfurters produced with non-gelled vegetable oils displayed increased firmness and chewiness values, attributed these attributes to a strengthened protein network as well as a decrease in the average lipid globule size. In this study, the increase in $G'$ values and hardness in Control 3 could also be attributed to its higher fat content (approximately 3% higher) compared to the OCC samples (Brighenti et al., 2008; Zetzl et al., 2012). In addition, all the Oleogel cream cheese (OCC) products showed a significantly higher storage modulus than the fat-free cream cheese sample.

### 3.5.1. Rheology: Temperature sweep

In order to better evaluate the rheological properties of the samples, a small deformation analysis was also performed and samples’ storage modulus ($G'$) was calculated.

Following the strain sweep test, all the samples were subject to a temperature sweep test to study their melting behavior as well. Fig. 5b shows the storage modulus values for RBW1 in comparison to the two commercial controls during the temperature sweep.

In order to demonstrate the effect of temperature on the samples melting properties, the obtained curves were divided into three sections and the slopes of the $G'$ curves at different temperature ranges during the temperature sweep are reported in Fig. 6. As illustrated in this figure, the full-fat commercial cream cheese sample displayed a steep decrease in storage modulus values when it was heated from 5 °C to 30 °C. Previous studies have attributed a rapid decline in $G'$ values (within this temperature range) to the melting profile of milk fat, entrapped in the casein network (Brighenti et al., 2008; Noronha et al., 2008). As shown in this figure, a more gradual decline in $G'$ values from 5 to 30 °C was noted in OCC samples. These results were expected since the OCC samples did not experience the melting profile of milk fat in this temperature range (5–30 °C). However the decline in $G'$ values was likely due to the increase in hydrophobic interactions, which could lead to the shrinkage of casein particles and thus a reduction in the modulus of elasticity (Brighenti et al., 2008). With the exception of the fat-free control, all the other samples exhibited a very slight decrease in $G'$ values during heating from 30 °C to 60 °C. This difference in $G'$ value of the fat-free control was likely due to the significant decrease in the sample fat content, as shown in Table 2. Moreover, the storage modulus values for the full-fat control (P1), the un-gelled samples, as well as all the OCC samples, did not differ significantly when melted from 30 °C to 60 °C. Interestingly, increasing the temperature from 60 °C to 80 °C induced an increase in the storage modulus of all the samples. At heating from 60 °C to 80 °C, the OCC samples had a slope that was more inclined compared to the commercial control sample, showing a higher elastic modulus for OCC samples. These results are in agreement with the Noronha et al. (2008) study that reported similar behavior for imitation cheese at temperatures ranging from 85 to 95 °C. They attributed this behavior to an increase in interactions between proteins, thus leading to increased protein coagulation as well as a strengthened casein network (Noronha et al., 2008). RBW1 had a higher content of milk powder than the full-fat and fat-free controls shown in Fig. 5b. In this study, the more inclined slope of the oleogel cream cheese samples at 60–80 °C could be caused by the increase in protein content through the addition of NFDM to the OCC products. Another contributing factor may be the potential increase in hydrocolloid gums in the OCC in comparison to the full-fat control (Brighenti et al., 2008). Most importantly, significant differences in storage modulus slopes were not observed between RBW oleogel samples and EC oleogel samples throughout the temperature sweep.

### 3.6. Sensory analysis

Since samples made with RBW showed comparable textural attributes, spreadability, hardness, stickiness, and adhesiveness to the full-fat control (P1), RBW1 was selected for sensory analysis.

The JAR test can provide insight into what extent the different attributes of the sample need to be modified, as seen in Fig. 7. In this test, no significant differences ($p > 0.05$) were observed between the RBW1 and the control cream cheese spreads for hardness, spreadability, or mouth-feel. This finding was a reflection of the results seen in the textural

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**Fig. 6.** Slopes of storage modulus values ($G'$) during a temperature sweep from 5 to 80 °C.
analysis, which indicated that the OCC samples made with RBWD had similar hardness and spreadability values to the full fat commercial control. The sweetness of RBW1 also matched with the sweetness of the control as “just about right”, which was unanticipated since cream cheese tends to have a tart or sour taste. Flavor and bitterness rankings for RBW1 and the control were the most significantly different between the two samples. The strength of flavor as well as bitterness for the RBW1 sample was rated as being too strong and needs to be improved through flavor enhancement for future testing. Correcting the bitterness may be a path to correcting the overall flavor of the samples. Further investigation into flavor development of the RBW1 product is necessary to enhance palatability.

4. Conclusion

The application of edible oleogels in combination with regulated ingredient formulation and processing conditions allowed for the creation of low fat oleogel cream cheese products. However, the use of different organogelators (vegetable wax vs. ethylcellulose) may have a significant impact on the structural properties of the final product. While many studies regarding the incorporation of oleogels into foods had combined previously made oleogels into their products, the oleogels used in this study were made simultaneously with the product instead of beforehand. Rice bran wax has been shown to provide textural properties more similar to the full-fat commercial control. Ethylcellulose cream (EC) cheese samples showed reduced adhesiveness and storage modulus (G’) values in comparison to the full fat control. The results indicated differences between the oleogel samples and the commercial controls in storage modulus (G’) values during a temperature sweep from 5 to 80 °C. Further steps may be necessary in order to create an OCC spread that displays similar storage modulus values throughout the entire temperature range that may be utilized for other applications such as heating, cooking, and baking. This work introduces the potential for the use of food grade organogelators in a variety of low fat dairy products and to enhance their fatty acid profile.

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