

Oleogels for food applications

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1. Introduction

Hard-stock fats contribute to many properties of final food products such as sensory, textural, physical structure, and aroma (Martins et al., 2018; Wang et al., 2016). Thus, hard-stock fats play a crucial role in the food industry to affect consumers' perception, positively. Different methods have been widely used to transform liquid oil into solid fat including hydrogenation, interesterification, or fractionation (Pehlivanoglu et al., 2018a,b). Regarding all these methods, hydrogenation has been used for decades to manufacture industrial oils and fats, which have better oxidative stability and plasticity. In hydrogenation, unsaturated fatty acids of vegetable oils are saturated with hydrogens. However, this process paved the way for trans-fatty acids, which are one of the many reasons that trigger cardiovascular diseases. Later, food manufacturers started to use the interesterification method, which offers to decrease the amount of trans-fatty acids significantly. All these alternative methods used for the production of fats were not capable of decreasing saturated fatty acids, which also called as a triggering effect for health problems (Chaves et al., 2017). Removing hard-stock fat to produce foods with low-saturated fat could cause uncharacteristic sensory and physical changes that would be unacceptable to the customers (Singh et al., 2017).

Oleogels, which can be a potential solution for the problems mentioned earlier, are the structured liquid oil matrix constructed with different gelling agents (known as *oleogelators* or *organogelators*) including long-chain fatty acids, vegetable-based waxes, mono, and di-glycerides, alcohols, and phospholipids See Chapter 30 for more information. To date, many studies have been reported that oleogels could be used in many different food formulations for different purposes such as replacing blend fat in baked foods, decreasing saturated fatty acid amount in meat and dairy products, and preventing oil migration in chocolate (Kaushik et al., 2017; Pehlivanoglu et al., 2018a,b). Main usages of oleogels in food technology was presented in Figure 31.1.

The popularity of conventional usage of oleogels in food formulations has been gradually diminished. Novel approaches of oleogel usage tend to focus on using them as a carrier agent for bioactive compounds. However, their absorbance in human digestive system is still not clear. The aim of this chapter is to give a brief account of potential food applications and outline future trends and concerns. This part of the study was subcategorized as oleogel applications in



FIGURE 31.1

Main usage purposes of oleogels in foods.

- (I) Meat products
- (II) Bakery products
- (III) Dairy products and
- (IV) Other applications.

Basic production steps of oleogels was simply schematized in Figure 31.2.

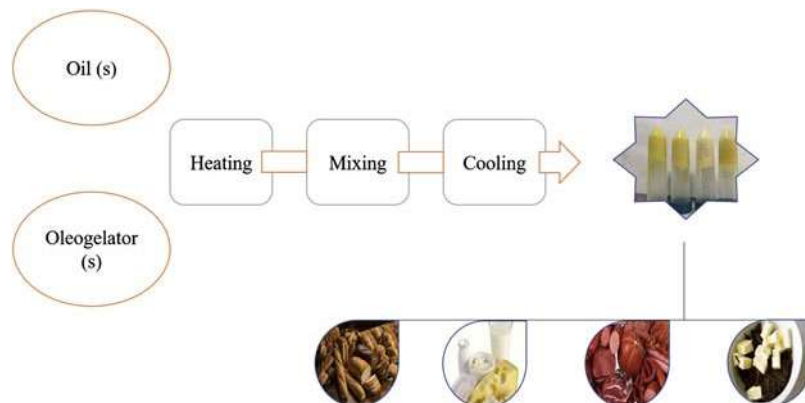


FIGURE 31.2

Food applications of oleogels.

2. Meat products

Consumers demand the improvement of the nutritional characteristics of meat products due to health concerns. Meats and meat products have a very important place in nutrition with their high protein content and nutritional value (Kayaardı and Gök, 2003). Cardiovascular diseases are linked to high-saturated fatty acid and cholesterol consumption (Enser et al., 1996). Food and Drug Administration (FDA) and World Health Organization and researchers (WHO) recommend avoiding foods containing a high amount of saturated fatty acids in the diet (De Vogli et al., 2014; McGuire, 2016; Pappa et al., 2000). For this reason, the meat industry focus on the feasibility of meat products, which have less animal fat. Animal fat (tail or inner fat) is used in various meat products (sausage, soudjouk and frankfurters, burgers) and contains a high amount of saturated fatty acids and cholesterol (Gök et al., 2011). The first approach was to use vegetable oils instead of animal fat (Asuming-Bediako et al., 2014). The usage of vegetable oils in meat products deteriorated the textural quality, appearance, and oxidation stability (Bloukas et al., 1997; Youssef and Barbut, 2011; Ospina-E et al., 2012; Bolumar et al., 2016). Therefore, the usage of oleogel, which is solid-like structured liquid oil, was studied recently (Idris and Dian, 2005; Pehlivanoglu et al., 2017). In this section, the usage of oleogels in meat products is discussed (Table 31.1).

The first study related to this topic was performed by Barbut et al. (2016a,b). The canola oil and oleogels prepared by canola oil, ethyl cellulose (8%, 10%, 12%, and 14%), and sorbitan monostearate (1.5%, 3.0%) were used for replacement of pork fat in breakfast sausages. Textural properties, color measurements, and sensory analyses were conducted. The results show that samples containing liquid canola oil and canola oil oleogels had lower hardness value than the control sample, which contained pork fat. The springiness value was negatively affected by oleogel addition. The replacement did not change significantly cohesiveness values of sausage but decreased chewiness. The result of colors test results showed that oleogels affected negatively lightness of sausage, but redness and yellowness were not affected. The samples containing organogels had lower juiciness and oiliness in sensory evaluation than those of control. The sensorial hardness decreased with the replacement of ethyl cellulose organogel. Although the replacement of pork fat with ethyl cellulose negatively affected color, texture, and sensory, the sorbitan monostearate gels helped to increase textural hardness, springiness, and gumminess. The sorbitan monostearate addition in formula did not change the L*, a*, b* values of sausage. Although sorbitan monostearate increased the textural hardness, it did not change sensorial hardness positively. Similar to ethyl cellulose organogels, the juiciness and oiliness parameters of samples containing sorbitan monostearate were found to be lower than those of control. The panelists evaluated the flavor of all of the sausage as dusty, but this behavior was more dominant in oleogel-based samples (Barbut et al., 2016a).

In another study, Wolfer et al. (2018) replaced pork back fat with rice bran wax oleogels in frankfurter-type sausages. The oleogels were prepared using soybean oil, 2.5% and 10% of rice bran wax and added into the frankfurter-type sausages. Proximate analysis (moisture, fat, and protein), thiobarbituric acid-reactive substances (TBARS) analysis, fatty acid profile, instrumental color analysis, texture analysis, and sensory analysis were studied. The replacement did not affect significantly moisture, protein, and lipid content of the final product. It was determined that pork fat, soybean oil, and oleogel did not negatively affect the technological quality of the raw frankfurter batter and samples with oleogels exhibited high emulsion stability values (between 98.51 and 99.08). The fatty

Table 31.1 Oleogel applications in meat products.

#	Purpose	Food or food related product	Oleogelator (s)	Oil (s)	Concentration (s)	Reference
1	Fat substitute	Beef burger	Beeswax	Sesame oil	5%–7.5%–10%	Moghtadaei et al. (2018)
2	Fat substitute	Frankfurter sausages	Monoglycerides and phytosterols	Sunflower oil	20% w/w and the monoglycerides/phytosterols mass ratios were 10:10 (1:1) and 15:5 (3:1).	Kouzounis et al. (2017)
3	Fat substitute	Frankfurters (Sausages)	Ethyl cellulose and Sorbitan monostearate	Canola oil	8% Ethyl cellulose + 1.5% Sodium monostearate, 8% Ethyl cellulose + 3.0% Sodium monostearate, and 10% Ethyl cellulose + 1.5% Sodium monostearate	Barbut et al. (2016a,b)
4	Fat substitute	Beef fat	Ethyl cellulose and sorbitan monostearate	Canola oil	8%–10%–12% and 14% ethyl cellulose and 1.5%–3% monostearate	Barbut et al. (2016a,b)
5	Fat substitute	Breakfast sausage	Ethyl cellulose and sorbitan monostearate	Canola oil	8%, 10%, 12%, and 14% ethyl cellulose and 1.5%, 3% sorbitan monostearate	Barbut et al. (2016a,b)
6	Fat substitute	Frankfurter sausages	Phytosterol and γ -oryzanol	Sunflower oil	10% and 20%	Panagiotopoulou et al. (2016)
7	Pork meat replacer	Pork meat + lean venison Salchichon (Sausages)	Soy protein organogel (olive oil + water + soy protein, 10:8:1)	Olive oil	10%	Utrilla et al. (2014)
8	Mechanical properties and potential stability	Meat sauces	Myverol, Policosanol	Sunflower oil, olive oil	0.5%, 2.5% Myverol, 0.5%, 2.5% Policosanol	Lupi et al. (2014)
9	Saturated fat reduction	Frankfurters	Ethyl cellulose	Canola, soybean, and flaxseed oil	10% ethyl cellulose and 90% vegetable oil	Zetzel et al. (2012)

acid profile analysis indicated that all soybean oil and soybean oleogels-consisting samples had higher essential polyunsaturated fatty acids such as linoleic (18:2n6) and α -linolenic (18:3n3) and had lower saturated fatty acid amount including stearic (18:0) and palmitic (16:0).

Regarding color properties, pork fat sample had lower L^* value, but higher a^* value than those of samples containing soybean oleogel. Although sensory analysis showed that the addition of oleogel and soybean oil did not affect aroma of cured frankfurter sausages, the flavor of cured frankfurter sausages was reduced with the replacement of pork fat. Texture analysis indicated that the replacement of pork fat did not significantly change the firmness, chewiness, and springiness ($P > .05$). The sample containing pork fat, soybean oil, and 2.5% rice bran wax treatments had similar lipid oxidation values ($P > .05$), but the sample with 10% rice bran wax sample provided higher lipid oxidation value than that of pork fat sample.

Similarly, da Silva et al. (2019) investigated the usage of oleogels prepared with pork skin, water, and high oleic sunflower oil instead of pork back fat in Bologna-type sausage. The technological, nutritional, oxidative, and sensorial properties were determined. The oleogel addition increased emulsion stability and decreased the cooking loss of final product. Although the replacement boosted the ratio of oleic acid, this treatment did not change oxidative stability. The reformulation of pork back fat by oleogel induced the reducing the fat content of the product. The lipid replacement did not significantly change the ash content of Bologna-type sausages ($P < .001$).

On the other hand, the reformulation decreased nearly 10% cholesterol levels. Even though the oleogel treatment increased hardness and chewiness, it did not change springiness and the cohesiveness of the Bologna sausages. The substitution increased L^* and b^* values and decreased a^* value. The reformulation of fat content decreased the pH of the product except for 25% replacement ratio. The fat content and Thiobarbituric acid-reactive substances (TBARS) values of oleogel-based sausages were found to be lower than those of pork back fat containing the sample. The oleogel addition did not change the water activity (a_w) values. As expected, unsaturated fatty acid content increased. The sensory analysis displayed that between the 25% and 50% replacement levels and the control group did not differ from each other regarding color, aroma, flavor, texture, and overall acceptance. The 75% and 100% substitution level oleogel treatments decreased textural acceptance. Therefore, the results indicated that substitution of pork fat content declined fat ($\sim 16\%$ fat, $\sim 29\%$ reduction), cholesterol (40 mg, $\sim 10\%$ reduction), and energy value (~ 210 kcal/100 g, $\sim 21\%$ reduction) (da Silva et al., 2019).

The replacement of beef fat with different organogels ranging 0%, 20%, 40%, 60%, and 80% in frankfurter sausage was studied. Canola oil structured with ethyl cellulose and sorbitan monostearate in different proportion (8% ethyl cellulose + 1.5% sorbitan monostearate, 8% ethyl cellulose + 3.0% sorbitan monostearate, and 10% ethyl cellulose + 1.5% sorbitan monostearate). The substitutions of beef fat with organogels caused high hardness values (texture profile analysis and sensory) of frankfurters prepared using canola oil treatment than that of the sample containing beef fat. The chewiness values did not affect by replacement of beef fat with organogel except, but canola oil addition was found to be effective. The incorporation level did not affect the cohesiveness value of samples. The proportion of 8% ethylcellulose + 1.5% sorbitan monostearate sample and 8% ethyl cellulose + 3.0% sorbitan monostearate sample did not affect hardness and springiness value but their value lower than canola oil treatment. The substitution of organogel did not affect shear force significantly. It was determined that canola oil treatments had higher smokehouse yield than that of control and the cooking loss decreased with increasing the proportion of organogel. The result of the

sensory analysis indicated that canola oil treatment increased hardness and this result appeared to be correlated with texture analysis. However, canola oil oleogel addition decreased the hardness. The replacement ratio increased oiliness comparing to that of control (Barbut et al., 2016b).

Panagiotopoulou et al. (2016) replaced pork back fat with sunflower oil oleogels manufactured by phytosterol and γ -oryzanol at different concentrations (10% and 20%) in frankfurter sausages. The sausages were reformulated with 20% total fat content. The reformulation was carried out with 10% pork back fat and 10% reformed sunflower oil in the form of organogels or organogel-in-water emulsions containing a variable proportion of γ -oryzanol and phytosterols in eight treatments and control treatment had 20% pork back fat. The results showed that substitution of pork fat did not affect pH and lipid oxidation level of product. The instrumental color analysis indicated that reformulated sausages with organogels had not different L*, a* and b* value regarding external surface compared to control sample. Furthermore, the substitution of pork fat with organogel did not affect textural parameters, but emulsion treatments had lower chewiness, hardness, and gumminess values than those of control sample. The results showed that the 60:40 sterol:oryzanol ratio was more convenient than other treatment to obtain a firm and solid fat, but the 30:70 sterol:oryzanol ratio was convenient for stabilizing with regard to organogel-in-water emulsions (Panagiotopoulou et al., 2016).

Another study related to the replacement of pork fat with olive oil organogel in venison salchichon, which is a traditional Spanish dried sausage produced from venison. The research was conducted with six samples; these were control (75% lean venison and 25% pork meat) and oleogel-based samples containing 3.75%, 6.25%, 8.75%, 11.25%, and 13.75% structured olive oil (organogel) used instead of pork meat. Organogels produced by emulsifying olive oil with soy protein concentrate and mineral water in a ratio of 10:1:8, respectively. Physicochemical analysis (pH, a_w , moisture, fat and protein content, color parameters, acidity index, and thiobarbituric acid-reactive substances), and sensory analysis were conducted in the study. The processing loss value decreased with the addition of olive oil. It was determined that organogel treatment decreased water loss of product. The moisture content analysis indicated that higher content olive oil samples showed higher moisture content than that of the control sample, but there were no differences at the end of ripening. The pH value decreased with increasing content of olive oil. It was concluded that the samples containing olive oil samples had higher fat content than the control sample. The samples containing olive oil had a lower TBARS value at the first day; their TBARS value reached the highest level toward the end of ripening period. The results showed that organogels containing structured olive oil range between 3.75% and 13.75% could be used instead of pork meat. It was also determined that more than 8.75% structured olive oil addition decreased the acceptability of venison sausages (Utrilla et al., 2014).

The usage of sunflower oil organogels structured with monoglycerides and phytosterols (15:5) instead of 50% pork back fat in frankfurter sausages was studied. Textural properties, lipid oxidation, instrumental color, and sensory evaluation were performed. Regarding textural properties, samples with the pork fat had higher values of hardness, brittleness, gumminess, and chewiness than those of the samples containing sunflower oil organogels. However, any significant differences in cohesiveness and elasticity values was not observed. Furthermore, pork fat samples presented higher a*, lower L*, and similar b* values compared to oleogel-based samples. The oxidation levels were found to be similar. The sensory analysis indicated that the samples had no differences at appearance, mouthfeel, taste, and overall acceptance. On the other hand, sample with pork lard added sample showed higher color and better smell than sample containing oleogel. In contrast with this, oleogel-based sample had a higher score than pork lard added sample in juiciness (Kouzounis et al., 2017).

Gómez-Estaca et al. (2019) investigated the potential usage of oleogels, produced from liquid oil (olive oil, linseed oil, and fish oil), ethyl celluloses, and beeswax, as a substitute for pork back fat in pâtés. Color measurements, textural properties, and lipid oxidation analysis and sensorial properties were determined. The results indicate that samples containing beeswax oleogel did not affect sensory parameters significantly compared to the samples containing pork back fat, but ethyl cellulose added samples had lower scores from the color, taste, and overall acceptability parameters of the pâtés. Color values decreased with the replacement of pork back fat. Especially, the ethyl cellulose added samples had lower than other samples. Cooking loss and water loss values were not affected by oleogels. Ethyl cellulose oleogels increased the TBARS values of pâtés.

Another investigation of the possible usage of sesame oil structured with beeswax as a replacement of animal fat (0%, 25%, 50%) was carried out. The replacement was carried out with beeswax at 10% concentration. Proximate composition, texture, color, fat absorption, cooking loss, shrinkage, microstructure, oxidative stability, and sensory acceptance were studied. The oleogel addition in raw beef decreased hardness, gumminess, and chewiness. The results showed that oleogel addition decreased cooking loss and fat absorption of a beef burger. The replacement of animal fat negatively affected cooking shrinkage and lipid oxidation values. The proportion of oleogel did not affect moisture, protein, fat, and ash content of raw burgers whereas moisture and fat content displayed difference with substitution levels in cooked burgers. The addition of beeswax into the product declined L^* value, and the intensity of L^* value was affected directly with the substitution level of animal fat. However, a^* and b^* values of cooked burgers did not display any difference with the substitution ratio. The rheological results exhibited that G' values of beeswax oleogel-based samples were found to be lower than that of animal fat. Microstructure analysis indicated that animal fat including beef burgers displayed smaller fat globules and uniform size.

On the other hand, samples containing oleogel appeared to have small and large-sized fat globules. The oleogel addition filled the void spaces in the beef burger structure. Sensory analysis showed that there was no difference in texture and color of the burgers, but the oleogel containing samples had higher flavor grades than the control sample from the panelists (Moghtadaei et al., 2018).

3. Bakery products

As the structure of human society develops, the average people's daily diet changes dramatically as well. The usage of food additives increases significantly with more and more processed foods in the market, so that bakery products also contain a variety of food additives such as emulsifiers, color retention agents, enzymes, and oxidizing agents. Oils and fats are one of the most important ingredients in baked products, which give the baked product a rich, soft, unique flavor, and improve the acceptability of the gluten and grain texture. Especially in a yeast dough, oils and fats play an emulsifier-like role for water retention. Therefore, they are related tightly to the texture, taste, and flavor of backed products and have an irreplaceable position in the baking industry. Currently, hydrogenated oil is the major ingredient in margarine, butter, smear, and spread products such as wafer biscuits, smear cream, pies, and pastry. The amount of trans-fatty acids in these products is usually higher than the standard. Meanwhile, these products also contain a high amount of saturated fatty acids. Many studies showed that people consume trans-fatty acids and saturated fats too much through diet resulting in the adverse effects on human health, such as increasing the risk of diabetes and obesity

to cause metabolic syndrome such as cardiovascular diseases (Mozaffarian et al., 2006; Mensink and Katan, 1990). Therefore, UN Food and Agriculture Organization (FAO) and WHO propose the daily intake of trans-fatty acids and saturated fatty acids should be less than 1% and 10% individually (Joint, 2010).

Edible fats provide foods not only a unique flavor but also good mouthfeel and appearance. They also have special functional properties in food processing. For example, in baked goods, it has the characteristics of the coating film, emulsion, and shortening. It is quite a challenge of researchers and food producers to reduce the amount of trans-fatty acids and saturated fatty acids in baked products and also maintain the original texture and flavor to fulfill the demand of consumers for healthy and tasty products. Therefore, the development of low or zero trans-fatty acids and low-saturated fatty acid foods is very important. In recent years, more and more studies focus on gel solidification of vegetable oil and its technology. When adding small organic, which is called oleogelator, to vegetable oil with certain processing conditions such as heating or cooling, vegetable oil is able to form a gel-like oil called oleogel. Organogelators, mostly waxes, can usually contribute the oleogelation during gelation of edible oils. The feature of oleogel contains the semisolid like viscoelasticity and low trans/saturated fatty acids so that it can be widely used in foods, medicine, cosmetics, etc. (Hughes et al., 2009). In this part of the chapter, all kinds of bakery products will be reviewed such as bread, cakes, muffins, and noodles. Their materials, methods, and results of physicochemical properties and food composition analysis also will be discussed (Table 31.2).

Monoglyceride (MG), organogel (apolar), and hydrogel (polar) containing sunflower oil replace palm oil in sweet bread to reduce the total saturated fat content 81% (w/w) in the product. When sweet bread is made with a monoglyceride organogel, the distribution of inhomogeneous lipid is less leavened and has a firmer structure. Besides, Bread containing monoglyceride hydrogel showed its staling during 14-day storage reduced significantly in comparison with bread with monoglyceride organogel. The result displayed 5% monoglyceride organogel and hydrogel in sunflower oil may involve in oil networking to interrupt its interaction with other small molecules and improve softening and antistaling (Calligaris et al., 2013).

Shortening is a type of solid fat at room temperature and mostly made from vegetable oils. It can produce crumbly texture in the cooking and baking process. Because it can shorten gluten in wheat and inhibit the gluten to form long tough strands in the dough to provide a light texture, the substitute of shortening would have imitated this functionality to contribute great plasticity for spreading into thin dough films certainly. Moreover, the viscosity of the shortening substitute should be similar to that of the dough, and the working temperature of the dough must be lower in comparison to the melting point of shortening substitute.

The modification of Coasun formula with rice bran wax, carnauba wax, candelilla wax, and sunflower wax in fully hydrogenated soybean oil is studied for puff pastries and baked goods. Coasun is a low-saturate, zero trans, oil-in-water structured emulsion used in baked industry for years. After modification, the oil-in-water emulsion not only enhances the mechanical strength of the system by behaving like a cellular solid but also the multilayer wall in fat with proper hydration to provide stability of products. The elasticity of coasun containing a solid fat increased to allow the formulations of the emulsion to the use as laminate fat substitutes at 20°C (Blake and Marangoni, 2015).

On the other hand, a shortening alternative also was made by canola oil structured with candelilla wax at two levels 3% and 6% w/w to produce solid-like properties of the oleogel. When cookies are prepared with this oleogel, their content of unsaturated fatty acid increased to 92% than the control

Table 31.2 Oleogel applications in bakery products.

#	Purpose	Food or food related product	Oleogelator (s)	Oil (s)	Concentration (s)	Reference
1	Shortening mimetics	Cake	Carnauba wax	High Oleic Sunflower Oil	5%	Pehlivanoglu et al. (2018)
2	Fat substitute	Muffin	Hydroxypropyl methylcellulose	Sunflower oil	1%	Oh and Lee (2018)
3	Shortening replacer	Cake	Rice bran wax, beeswax, and candelilla wax	Sunflower oil	10% each	Oh et al. (2017)
4	Shortening replacer	Muffins (aerated baked goods)	Candelilla wax	Grape seed oil	8%	Lim et al. (2017b)
5	Deep-fat frying medium replacer	Instant fried noodles	Carnauba wax	Soybean oil	5 and 10 g/100 g (w/w)	Lim et al. (2017a)
6	Replacement for shortening	Baked goods	Carnauba wax	Canola oil	9:1 ratio	Kim et al. (2017)
7	Shortening replacer	Cookies (short dough product)	Carnauba wax, Candelilla wax	Sunflower oil	2.5%, 5% Carnauba wax 2.5%, 5% Candelilla wax	Mert and Demirkesen (2016b)
8	Replacement for shortening	Baked product	Candelilla wax	Canola oil	3% and 6%	Mert & Demirkesen (2016a)
9	Organogel is incorporated in a margarine formulation to determine the feasibility of cookies	Cookie	Sunflower wax, rice bran wax, beeswax, and candelilla wax	Olive oil, flaxseed oil, soybean oil	2%, 4%, 6%, 8%, and 10%	Hwang et al. (2016)
10	Shortening replacer	Cookies	candelilla wax	canola oil	3% and 6% (w/w)	Jang et al. (2015)
11	Shortening replacer (laminated fat substitute)	Puff pastry products (Coasun with croissant and danishes)	Rice bran wax, carnauba wax, candelilla wax, and sunflower wax	Fully hydrogenated soybean oil	1%–15% (w/w), oil 50%–77% (w/w).	Blake et al. (2015)
12	Palm oil replacer	Sweet bread	Monoglycerides	Sunflower oil, palm oil	5%	Calligaris et al. (2013)
13	Replacement for shortening	Cookie	Beeswax and sunflower wax	Hazelnut oil	5%	Yilmaz and Oğutcu (2015a,b)

shortening samples at 47.2%. Besides, this oleogel viscosity was more sensitive to temperature change and less firm at room temperature in comparison with control shortening. The cookies containing oleogel had lower values of snapping force and greater value of spread factor. These properties showed quality attributes of the cookies have desirable spreadability and softer eating characteristic (Jang et al., 2015).

Margarine is mainly made from water and vegetable oils such as canola, olive, or sunflower oil usually. Sometimes margarine contains skim milk and emulsifiers to keep everything blended. The most important feature of margarine is higher content of monounsaturated and polyunsaturated fatty acid than butter. Most of the margarine has less saturated fat 10%–20% than regular butter saturated fat 52%–65% (Gebhardt et al., 2008).

The replacement of conventional margarine is made by several vegetable oil and natural wax for cookies preparation. Organogels were prepared by three different vegetable oils (olive oil, soybean oil, and flaxseed oil) and four different waxes including beeswax, candelilla wax, sunflower wax, and rice bran wax. The organogel containing sunflower wax and rice bran wax offered the greatest hardness in cookie dough. Nevertheless, the organogels with different waxes and vegetable oils do not influence significantly to fracturability of cookie, hardness and spread factor. The fat portion may be less important in cookies properties than the networks of flour formation (Hwang et al., 2016).

In the study of Behic Mert and Ilkem Demirkesen, oleogels were prepared by adding candelilla wax to canola oil at two different concentrations (3% and 6% w/w) for the partial shortening replacement in cookies. Oleogels were blended with a commercial bakery shortening before cookie baking process. Cookies containing oleogels had more extensibility and less hardness than samples with commercial shortening. However, the samples containing shortening are still softer than the sample containing the shortening completely replaced by oleogel. Accordingly, replacing shortening with oleogels partially improved not only physical properties of the cookies significantly but also allowed obvious reduction of saturated fat content in cookies (Mert and Demirkesen, 2016a).

Meanwhile, they also performed another oleogel study to determine the potential application of shortening replacement by using two different oleogels containing carnauba wax and candelilla wax with sunflower oil in a short dough product. The oleogels at high wax concentration allow baked products with more acceptability compared to those at low wax concentration. Further, samples containing those two waxes provided higher spread ratio and firmer texture than products containing a commercial shortening agent (Mert and Demirkesen, 2016b).

Fig. 31.3A comparison of the bakery product prepared with traditional liquid plant oil or shortening (left) and oleogel (right). The sample containing liquid vegetable oil or shortening have more air cells and porous structure (Figure 31.3). However, the bakery products prepared with the oleogel are less leavened and firmer structure. Besides, the specific volume of the samples containing oleogel is lower than the one containing liquid oil or shortening.

Oleogels also can affect the volume of baked products, and the aerated texture provides special mouthfeel for consumers. Therefore, preventing volume loss is one of the technical challenges when replacing solid fat with oleogels in the bakery industry. Oleogel sample was prepared with canola oil and carnauba wax (10% w/w) to replace shortening in baked cake. The porosity and fragmentation index of cake crumbs decreased when the content of oleogel increased in shortening replacement. The specific volume of cakes was maintained to hold air cell in cake batters by shortening replacement with the canola oil–carnauba wax oleogel at up to 50%. The quality of cake can be maintained when the shortening contains the oleogel up to 25% in cake formulation (Kim et al., 2017).

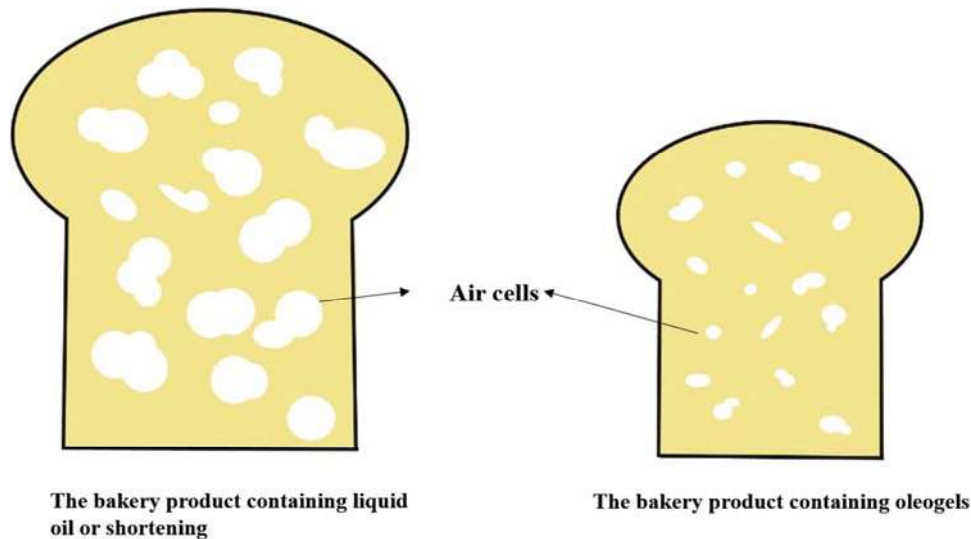


FIGURE 31.3

Differences between bakery products prepared with oleogel and shortening.

With the development of diet and health consciousness, more and more people do not consider deep fat frying foods. Nowadays potatoes, onion rings, donuts, squids, chicken, turkey, and even noodles are commonly cooked in a deep fryer. Deep frying in hot oil may burn people and start fires due to the enormously dangerous high temperature. Furthermore, oxidation is one of the unpleasant reactions for the frying process because it causes adversely influence to consumer acceptability, quality, and nutritional properties of fried products. Hence, improvement of oxidative stability and prevention of nutrition loss in fried products must be truly considered by the manufacturer of fried food products.

The instant fried noodle is a very common snack all over the world especially in East, Southeast Asia, and the Indian subcontinent region. Deep-fat frying plays a very important role during the processing of instant fried noodle because this frying process not only removes not extra moisture from noodles to extend its shelf-life but also contributes unique flavor and texture to the noodle product. It becomes a very popular ready-to-eat product because there are several advantages such as its convenience of preparation, widely acceptable and irresistible flavor, low price, portable, long shelf-life, and simple storage.

However, the instant fried noodle also has some adverse concerns. For example, it usually contains high calories and lack of essential nutrients. Too much food additives are added into the sauce and flavor powder in the noodle products to cause huge consumer concerns extensively. Furthermore, the deep fry oil is commonly used palm oil, and it has high saturated fat content. Jeongtaek Lim and his colleague studied on the oleogel prepared by soybean oil structured with carnauba wax at two levels (5% and 10% w/w) to develop a semisolid oil product for instant fried noodles. When the oleogels was used for frying noodles, the saturated fat content of fried noodles is extremely reduced to 19% compared to 54% in noodles prepared from palm oil. The unsaturated fatty acid content of oleogel

increased to 81% compared to 46% in palm oil. Moreover, the deterioration and rancidity of oil can be retarded more effectively by the solid-like oleogels to improve the oxidation stability than the use of liquid soybean oil, but palm oil still has the highest oxidation stability in comparison to soybean oil and the oleogel. Oil uptake of oleogel is the lowest than palm and soybean oil, and it showed the potential of oleogel could be used for low-fat instant noodle products (Lim et al., 2017a).

Recently, grapeseed oil is considered a healthy and beneficial oil because it is a good source of vitamin E and high polyunsaturated fatty acid content, mostly omega-6 fatty acids. According to American Heart Association and American Academy of Dermatology, vitamin E generally can help reduce free radicals to improve the skin or hair health, and even antiaging as well. Lim and his colleague also worked on grapeseed oil for oleogel preparation by adding candelilla solid wax. Afterward, they used the oleogel to replace the shortening for preparing muffin batters. As a result, the oleogel blending with shortening at a ratio of 1:3 provided muffin batters to display more desirable quality attributes such as greater shear-thinning behavior, lower viscosity, and less elasticity (Lim et al., 2017b).

The formulation of wax-based watery and water-free oleogels was developed with high oleic sunflower oil constructed at 5% carnauba wax. The cake containing oleogels has rich unsaturated fatty acids and lower solid fat content without undesirable flavor and texture. Thus, the cake including oleogels had similar results with the control sample including shortening only based on the sensory evaluation. Besides, optical properties of oleogels and shortening by color measurement are also very similar. As the cakes, batter containing many small air cells and the volume of baked also affect the consumer preference (Felisberto et al., 2015). The most volume of the cake was found in samples containing with oleogel prepared from shortening and cottonseed oil. Furthermore, watery oleogels can produce greater volume and specific volume in samples than water-free oleogels (Pehlivanoglu et al., 2018).

Rice bran wax, candelilla wax, and beeswax were used as oleogelators. All of the waxes are added at 10% w/w to sunflower oil for preparing oleogels as a fat replacer in cakes. The cake batters with wax-based oleogels had lower viscoelastic parameters than an order of magnitude, and the samples containing beeswax allowed the highest viscoelastic parameters. Rice bran wax and candelilla wax are more dominant in the viscoelastic properties of cake batters than beeswax. Moreover, the specific volume in baked products usually is affected negatively by shortening replacement because fats play an important role in aeration. The more air cells and porous structure showed higher specific volume in food products. Therefore, the lower specific volume commonly showed more hardness and chewiness cakes because the structure with compact and dense cells in cakes provided harder texture. When the shortening replacement contained beeswax oleogels, the specific volume of cakes is similar with the sample with the shortening control. As a result, the cakes prepared by oleogels demonstrated higher unsaturated fatty acids content at 82.5%–86.5% and lowered saturated fatty acids content at 13.8%–17.5% in comparison with the sample with shortening control. The sample with high unsaturated fatty acids content may contribute the less oxidative stability for the shelf-life of products. Cakes containing beeswax had softer texture, higher specific volume with fine air cells in crumbs, and quality without nutrition loss (Oh et al., 2017).

For oleogel preparation, not only small molecules like waxes but also modified cellulose are used as an oleogelator. Sunflower oil structured by hydroxypropyl methylcellulose at 4% w/w was used for the preparation of solid-like oleogel to replace a shortening agent at four different levels, 25%, 50%, 75%, and 100% w/w in muffins. The muffin batters containing oleogels contribute the higher flow

behavior index than the sample with shortening control. The flow behavior index also increased with higher hydroxypropyl methylcellulose content in oleogels to cause lower shear viscosity. Furthermore, the consistency index decreased when oleogels had lower hydroxypropyl methylcellulose content. In addition, the loss of specific volume was only found significantly when the shortening in the muffin was replaced by oleogels at 75% and 100% level. It showed the structure of air cell was less compact and dense up to a 50% oleogel as a shortening replacer. For color measurement of muffins, the sample with oleogels provided higher redness, yellowness, and darkness than control sample with shortening. The rheological properties of muffins were determined by X-ray tomographic analysis. As a result, the pore size uniformity decreased and the pore size increase when samples contain a higher content of the oleogel replacement of shortening. In consequence, the application of this oleogel could be used practically in the industry because there is no negative influence on their texture, viscoelasticity, porosity, and volume (Oh and Lee, 2018).

Yılmaz and Oğutçu (2015a) investigated the physicochemical, textural, and sensory properties of the cookies produced by the commercial bakery shortening, and the cookies were compared with the cookies produced by using hazelnut oil oleogel (beeswax and sunflower wax 5%). Accordingly, the L^* and b^* values of the cookies produced with oleogel products were found to be different from the cookies produced by shortening and the a^* value was similar. The solid fat content of the commercial shortening used in the study (35°C, 30%) was observed to be higher than that of hazelnut oil (35°C, 2%–4%). Although the diameters of the cookies produced by oleogel were found to be similar to the cookies produced by shortening, the weight and thickness values were different. The pH and water activity values of the cookies produced by oleogel were found to be different from the cookies produced by shortening. The ash amounts of the cookie samples were found to be between 0.53% and 0.79% and the samples were similar regarding the amount of ash. The energy values of the cookie samples were determined as 5360.75 cal/g for the control, 5734.60 cal/g for the beeswax-based sample, and 5794.30 cal/g for the sunflower-based sample. The highest crispiness was found to be in oleogel-contained cookies. Beeswax-containing cookies were found to be texturally hard and brittle than control and sunflower wax oleogel-based samples. The consumer preference results of the cookies produced with oleogels were found to be quite similar to the cookies produced by using shortening.

4. Dairy products

Dietary trans- and saturated fats cause cardiovascular ailments and metabolic syndromes. To increase the consumption of polyunsaturated fatty acids is recommended to prevent these adverse effects of trans- and saturated fats. The structural properties of many dairy food products such as ice cream, cheese, and butter are related to the structure of triacylglycerol in the matrix. Furthermore, some quality properties including stiffness, mouth sensation, and mechanical properties, which are the essential features desired by consumers, are provided by trans- and saturated fats. Due to the adverse effects of trans- and saturated fatty acids in dairy products, many studies were conducted to eliminate them using oleogels, which are promising materials to decrease saturated and trans-fatty acids in the final product (Schaink et al., 2007; Rogers, 2009; Toro-Vazquez et al., 2007; Hughes et al., 2009; Perneti et al., 2007a) (Table 31.3).

Moriano and Alamprese (2017) produced ice creams using sunflower oil organogels structured by phytosterols and γ -oryzanol and determined the color properties, viscosity, solid fat content, density

Table 31.3 Oleogel applications in dairy products.

#	Purpose	Food or food related product	Oleogelator (s)	Oil (s)	Concentration (s)	Reference
1	Oxidative stability and tocopherol content	Cheese	Rice bran wax	High-oleic soybean oil	9:1 ratio	Park et al. (2018)
2	Fat substitute	Ice cream	Phytosterols and γ -oryzanol	Cold-pressed sunflower oil	8 g/100 g or 12 g/100 g on oil basis	Moriano and Alamprese (2017)
3	Fat substitute	Cream cheese	Ethyl cellulose and rice bran wax	Soybean oil	10%	Bemer et al. (2016)
4	Replace solid fat content and create optimal fat structure	Ice cream	Rice bran wax, candelilla wax, or carnauba wax	Sunflower oil	10% each	Zulim Botega et al. (2013)
5	Fat substitute	Ice cream	Rice bran wax	High oleic sunflower oil	10%	Zulim Botega et al. (2013)

degree, and a volume increase of samples. Fat in the formulation was between 4% and 8%. As the amount of fat used in the ice cream increased, the density of the product, solid fat content, volume, and melting rate decreased significantly. The higher amount of gelator provided better volume increase, and it was stated that more gelator resulted in a better quality and melting time. The density and soluble solids were not affected by fat type. The viscosity of the ice cream containing with milk cream was found to be higher than that of the others. With the increasing shear rate, the viscosity decreased. Regarding color parameters, there were no significant differences observed. All ice cream samples exhibited good shape retention during melting. Furthermore, there were no significant difference in firmness values. The firmness value was affected directly by the fat amount. Overall, the ice cream sample containing 12% γ -oryzanol was found to be the most similar to the control.

Another dairy product was studied by [Bemer et al. \(2016\)](#). In the study, cream cheese was manufactured using ethylcellulose and rice bran wax oleogels, which are obtained using soybean oil and high oleic soybean oil. They investigated some physicochemical properties and compared them to those of full-fat and fat-free commercial cheeses. They examined the similarity test between oleogel cream cheeses and commercial control groups regarding spherical oil sizes with Confocal Laser Scanning Microscopy and found their microstructural properties to be successful. They also examined the fatty acid profiles of creamy cheeses to replace saturated fat with unsaturated fat alternatives. The total fat content of oleogel cream cheese samples was less than about 25% compared to that of full-fat industrial controls. The full-fat cream cheese sample was found to be the highest in moisture (%), fat (%), and nonfat solids content (%).

Regarding textural properties, in hardness and spreadability, there were no significant differences except for nongelled control. The samples containing ethylcellulose oleogels also showed less adhesiveness and storage modulus values than the full-fat control. The rice bran wax was found to be similar to full-cream cream in sensorial properties.

The researchers replaced milk fat with high oleic sunflower oil structured by rice bran wax in ice cream. Moreover, 80% saturated mono and diglycerides, and 20% polysorbate 80 (Polmo) were used for emulsification of ice cream. Standard ice cream measurements, cryo-scanning electron microscopy (cryo-SEM), differential scanning calorimetry, and transmission electron microscopy (TEM) were conducted. The rice bran wax provided a higher overrun score and resulted in a lighter sample and had higher textural and appearance score than those of a liquid oil treated sample. When emulsifier concentration increased, the protein adsorption of rice bran wax sample decreased. The addition of the emulsifier level increased, and the mean diameter of rice bran oleogel was increased. The addition of oleogel and emulsifier did not affect the meltdown stability of ice cream. Microscopy analysis showed that rice bran wax oleogel sample displayed larger fat droplets at the air cell interface compared to other samples and deteriorated the shape of air cells and fat droplets. Whereas the replacement of milk fat with rice bran wax-oleogel caused a weak structure in ice cream, the addition of emulsifier to rice bran wax-oleogel led to the formation of a fat globule network (Zulim Botega et al., 2013a). Effects of oleogel addition on ice-cream could be seen in Figure 31.4.

In another study, Park et al. (2018) produced cream cheese using high oleic sunflower oil oleogels solidified by rice bran wax and compared them to ungelled and two commercial cheese regarding oxidative stability and tocopherol content. Ungelled cream cheese and oleogel-based cream cheese had lower fat content compared to control ones. The saturated fatty acid content of commercial cheeses was found to be higher than those of ungelled and gelled samples. Regarding tocopherol contents, there were no significant differences in ungelled cream cheese and oleogel-based cream cheese. Total tocopherol content was found to be lower in commercial samples comparing to that of ungelled and oleogel-based samples. Storage time did not affect the tocopherol content in all samples. Volatile

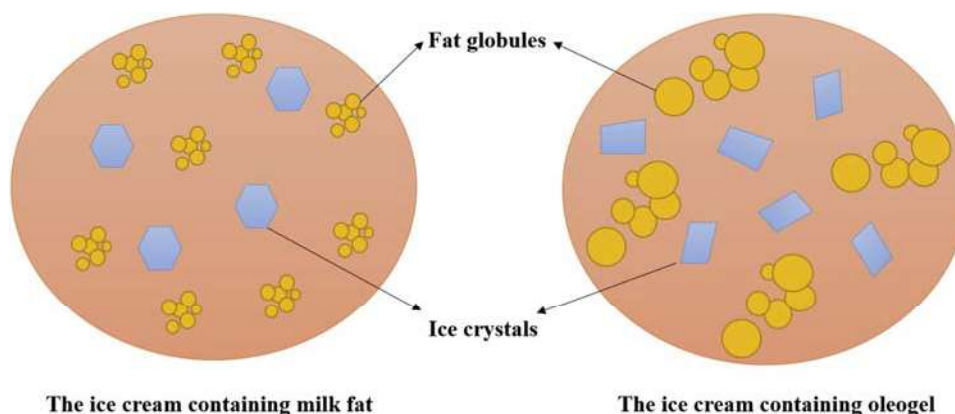


FIGURE 31.4

Differences between ice cream prepared with oleogel and milk fat.

compounds were found to be the highest in the oleogel sample, the second closest one was the oleogel-based cream cheese. It was stated that the amount of oxidation products was also comparable.

Zulim Botega et al. (2013b) replaced milk fat with high oleic acid sunflower oil oleogels (ratio of oil to wax 1:9) structured by rice bran wax, candelilla wax, or carnauba wax oleogels in ice cream. Furthermore, they examined the effect of emulsifiers, waxes, fat concentration, and processing conditions in ice cream. The ice cream sample containing rice bran wax oleogel, emulsified with glycerol monooleate, showed lower melting rate than that of rice bran wax oleogel and mono- and di-glycerides and 20% polysorbate 80 treatment. When compared structural integrity of emulsifiers, glycerol monooleate sample displayed a stronger structure than that of mono- and di-glycerides and 20% polysorbate 80. The sample containing rice bran wax oleogel emulsified with glycerol monooleate composed uniform spherical shape and interior crystals that were observed by TEM. The glycerol monooleate was found to be more a useful emulsifier compared to mono- and di-glycerides and 20% polysorbate 80. The increasing of the substitution level resulted in lower rates of meltdown and better shape retention. However 10% rice bran wax must be used for including a higher fat oleogel sample. When freezing applications were compared in the rice bran wax oleogel treated samples, continuous freezing showed stronger structural stability than that of batch freezing. Comparing oleogel systems in ice creams, rice bran wax included higher fat concentration and showed stronger shape retention and lower melt rate than those of candelilla wax and carnauba wax.

5. Other applications

In this part of the present chapter, other food applications of oleogels were outlined. Oleogels were added to different food products such as chocolate, peanut butter, or spreadable breakfast products for different purposes. In bakery, meat, or dairy products, while the main objective was to decrease the amount of saturated fatty acid content; in other applications, purposes were mostly oxidative stability, preventing oil migration, or delivering aroma and antioxidants except for spreadable products. In this regard, the following part includes the type, purpose of oleogel and gelator, and how to effect the final product (Table 31.4).

5.1 Spreadable products

The common methods for obtaining solid fats, which are one of the main ingredients of margarine, hydrogenation, interesterification, and fractionation. A well-known side effect of solidification processes is the high amount of saturated fatty acid and trans-fatty acids (Pehlivanoglu et al., 2017). Therefore, many studies have been conducted to decrease saturated fatty acid in margarine and shortenings using oleogels.

Yilmaz and Ogutcu (2014) manufactured oleogels containing olive oil, and beeswax and sunflower wax as gelator. Amount of oleogelator in the matrix was 3%, 7%, and 10%. Thermal properties, color properties, oil-binding capacity, solid fat content (SFC), morphological studies, X-ray diffraction analysis, texture analysis, and oxidative stability studies were conducted, and results were compared to those of breakfast margarine. L* values were increased with the increase of wax present in the matrix. L* values of both oleogels at all percentage were lower than margarine. Oleogels containing sunflower wax were more yellowish and luminous than the beeswax oleogels. Oil-binding capacity of oleogels

Table 31.4 Other oleogel applications.

#	Purpose	Food or food related product	Oleogelator (s)	Oil (s)	Concentration (s)	Reference
1	Margarine alternative	Breakfast margarine	Beeswax and sunflower wax	Virgin olive oil	3%, 7%, and 10%	Yılmaz and Ögütçü (2014)
2	Margarine alternative	Commercial margarine	Myverol (monoglyceride)	High oleic sunflower oil	Ranging 6%–14%	Palla et al. (2017)
3	Margarine alternative	Commercial margarine	Carnauba wax and monoglyceride	Virgin olive oil	3%, 7%, and 10%	Ögütçü and Yılmaz (2014)
4	Margarine alternative	Breakfast margarine	Beeswax	Virgin olive oil	5%	Ögütçü et al. (2015)
5	Fat substitute	Shortenings and margarines	Sunflower wax	Rice bran oil	1.0%wt	Doan et al. (2018)
6	Margarine alternative	Breakfast margarines and spreadable	Sunflower and beeswax	Hazelnut oil, virgin olive oil	5%	Yılmaz and Oğutçu (2015b)
7	Margarine alternative	Spreadable products	Sunflower wax, rice bran wax, candelilla wax	Soybean oil	Ranging 1%–6%	Hwang et al. (2013)
8	Margarine alternative	Breakfast margarine	Sunflower wax	Soybean oil, almond oil, canola oil, corn oil, flaxseed oil, grapeseed oil, olive oil, peanut oil, pumpkin seed oil, safflower oil, sesame oil, sunflower oil, walnut oil	3%, 5%, and 7%	Hwang et al. (2014)
9	Fat substitute	Chocolate spread	Monoglyceride, beeswax and propolis wax	Pomegranate seed oil	5%	Fayaz et al. (2017)
10	Fat substitute	Confectionery fillings	Beeswax	Rice bran oil, palm oil, hazelnut oil	1.5%, 2.0%, 2.5%, 3.0%, and 3.5%	Doan et al. (2018)

Continued

Table 31.4 Other oleogel applications.—cont'd

#	Purpose	Food or food related product	Oleogelator (s)	Oil (s)	Concentration (s)	Reference
11	Organogel as oil migration barrier	Filled chocolate products (hazelnut-nougat)	γ -oryzanol, β -sitosterol	Sunflower oil	10%, 25%	Wendt et al. (2017)
12	Gel structure and oxidative stability	Delivering agent	Beeswax	High oleic sunflower oil	2%, 4%, 6%, and 8%	Martins et al. (2017)
13	To increase bioactivity of phytosterol crystals	Yogurt	Phytosterol and γ -oryzanol	Sunflower oil	Ratio of γ -oryzanol to phytosterol 100:0, 80:20, 60:40, 40:60	Moschakis et al. (2017)
14	Fat substitute and aroma carrier	Spreadable products	Beeswax	Fish oil	5%	Yilmaz et al. (2015)
15	Antimicrobial agent carrier		Colloidal silica	Paraffin oil, olive oil	4.28%–8%	Kasparaviciene et al. (2018)

was measured above 99% and not affected by wax type. Furthermore, sunflower-based oleogels were crystallized faster than beeswax oleogels. The SFC values were increased with the increase of wax amount. The SFC value of 10% sunflower and 10% beeswax was the closest ones to the breakfast margarine.

Regarding thermal behaviors, melting temperatures and enthalpies of sunflower wax oleogels were higher than those of beeswax oleogels.

Furthermore, the melting temperature of oleogels was related to the amount of wax. The melting point of 3% beeswax oleogels was the closest to the breakfast margarine. The XRD patterns of both oleogels were found to be similar. Sunflower-based oleogels had longer fibrous crystals, which were the most consistent. In textural properties, sunflower wax oleogels were harder than beeswax oleogels. Furthermore, firmness values were found to be affected by wax concentration. For storage stability, the peroxide value of the samples was measured for 90 days. At the 60th day, the peroxide value of breakfast margarine started to increase. Wax concentration and type could not affect the peroxide value. Lower than 7% of beeswax and lower than 3% of sunflower wax oleogels could be used as a margarine alternative.

In a similar study, [Palla et al. \(2017\)](#) fabricated oleogels using myverol (monoglyceride) to determine the effect of temperature, gelator amount, the speed of agitation, and the cooling temperature, they designed the experimental procedure using Box-Behnken incomplete factorial design. Oil-binding capacity, textural properties, rheological properties, and microstructural properties were studied and compared to those of commercial margarine. Oil-binding capacity increased with the increase of myverol. At 11% (w/w), the highest oil-binding capacity was observed. At the highest myverol values, the speed of agitation also increased and resulted in a higher oil-binding capacity.

Furthermore, at the lowest preparation temperature, oil-binding capacity was found to be highest. With the increasing temperature values, oil-binding capacity decreased slowly.

Regarding texture properties, hardness value of samples was found to be between 0.4 and 2.95N. As the hardness value of margarine is approximately 1.6N, it could be possible to produce margarine-like products using this procedure. The maximum hardness value was observed in the both highest temperature time and speed of agitation. On the contrary, at the lower agitation and preparation, temperature harness values were not observed low. As expected, a higher amount of gelator caused increase in hardness values. Cohesiveness value of oleogels was found to be lower than that of margarine. Cohesiveness decreased with the increase of myverol amount and hardness. Higher adhesiveness values were obtained by combining high speed of agitation and a low temperature of gel preparation. The increase of the gelator concentration increased the fracturability values. Increase in both hardness and fracturability means that oleogel is becoming firmer. In angular frequency tests, all oleogels displayed similar behavior, that is, elastic modulus was higher than the viscous modulus. This type of behavior is known as a gel-like structure.

Another study of oleogels as the alternative spreadable product was conducted by [Ögütçü and Yılmaz \(2014\)](#). In the mentioned study, they fabricated oleogels using virgin olive oil and, carnauba wax and monoglyceride as gelators. Concentrations of gelators were 3%, 7%, and 10%. Color values, textural properties, morphological studies, oxidative stability studies, and thermal properties were conducted and compared to those of margarine. The a^* and b^* values of the oleogels were found to be increased with the increasing amount of gelators. Oil-binding capacity of monoglyceride-based oleogels was higher than that of carnauba wax samples. At the 3% concentration of both gelators, only monoglyceride oleogels started to crystallize.

On the other hand, significant differences were not observed in the crystal formation time at 7% and 10% concentration. At 20 and 35°C, solid fat content value of carnauba wax-oleogels was found to be lower than that of monoglyceride.

Regarding thermal properties, monoglyceride oleogels had a similar melting and crystallization temperatures to breakfast margarine. The firmness value of carnauba wax-oleogels was found to be higher than that of monoglyceride oleogels during 90-day storage. During storage, the firmness value of monoglyceride gradually decreased, while any significant changes were not observed in carnauba wax oleogels. Comparing the concentrations of gelators, 10% carnauba wax samples had higher firmness values than 3% ones. However, in monoglyceride samples, there were no significant differences at different concentrations. Similar results were obtained in stickiness values. The stickiness value of carnauba wax sample was found to be higher than monoglyceride-based oleogels and during storage stickiness value of monoglyceride oleogels tend to decrease. Although the carnauba wax oleogels had dense and rod-like crystals, monoglyceride oleogels had rosette-like or spherulitic crystals. Overall, the 7% monoglyceride containing oleogel could be an alternative to margarine in the textural and thermal properties.

Ogutcu and Yilmaz (2014) investigated the feasibility of watery oleogels produced by virgin olive oil, beeswax, and emulsifiers as an alternative spreadable product. The amount of wax, emulsifiers, and water was determined by pretrials. Four different types of emulsion, which contained emulsifiers (xanthan gum, tween 20 and tween 80), beeswax, water, oil, and other ingredients, and beeswax oleogels were produced and physicochemical properties of these samples were compared to those of breakfast margarine. Xanthan gum was found to be suitable in the gelators, and tween emulsifiers and hydrocolloid mixtures exhibited simultaneous emulsifying ability and contributed to the formation of oleogels synergistically. The melting temperature of oleogel and oleogel-based emulsions had the melting points ranged 52.29–57.52°C. They reported that xanthan gum in the formulation could decrease the melting point. Solid fat content was correlated to the wax amount in the matrix.

Furthermore, the addition of wax resulted in decreasing the crystallization time. As expected, the firmness value of samples at 4°C was higher than that of samples at 20°C. At all temperature values, the firmness value of breakfast margarine was found to be higher than the other samples.

On the other hand, oleogel-emulsion samples were softer than the beeswax oleogel. The stickiness value, another textural parameter, was found to be higher than those of all samples. It was observed from polarized light microscopy that gel-emulsion samples had the needle-like crystals. Furthermore during storage, an increase was monitored in water droplet size. From the FTIR spectra, intermolecular and intramolecular hydrogen bonds were monitored. The colors of oleogel samples were found to be stable during storage. All samples displayed opaque and greenish yellow. After 90 days of storage, the peroxide value of breakfast margarine was found to be lower than that of oleogel samples at room temperature.

Doan et al., (2018) replaced interesterified palm-based fat with sunflower wax, rice bran oil in margarine, and shortening. The researchers conducted thermal behavior, solid content, polarized light microscopy, Cryo-SEM, powder X-ray diffraction, texture analysis, and rheological behavior. The usage of 1.0% wt sunflower wax increased the solid content of shortening. The replacement of interesterified palm-based fat with oleogel decreased up to 40% of interesterified palm-based fat in the hybrid fat phase but keeping the same hardness and rheological structure. The substitution of palm-based fat with oleogel positively caused crystallization of samples. The thermal behavior analysis showed that sunflower wax was crystallized earlier and behaved as nucleation sites for the

crystallization of palm fat throughout cooling of the hybrid shortenings. Oleogel treatment was enhanced to stabilize the water droplets inside the wax-based crystalline network without flocculation during shear cooling.

Yılmaz and Ögütçü (2015b) fabricated hazelnut oil and virgin olive oil oleogels, solidified by sunflower and beeswax, as a potential replacement to breakfast margarine and spreadable. Furthermore, these oleogels were aromatized with butter aroma. Wax concentration was 5% for both gelators. Prepared oleogels' color (L^* , a^* , and b^*) values, crystal formation times, oil-binding capacities, solid fat content values, peroxide value, free fatty acid content, iodine value, calorie, crystal structures, thermal, textural, and sensorial properties were determined. All color parameters were found to be the highest in commercial butter sample, whereas sunflower wax-based oleogels were the second highest ones. In the study, it was determined that crystal formation times of sunflower wax and beeswax was 3.5 min and 6.5 min, respectively. The solid fat contents of the hazelnut oil oleogels produced by beeswax were lower than that of the oleogels produced with sunflower wax at 35°C. The butter-flavored hazelnut oil oleogels were similar regarding peroxide number and iodine numbers, but different from the butter sample. The melting temperature of hazelnut oil-sunflower wax oleogels was found to be higher than that of other samples. Olive oil sunflower wax oleogels had the highest energy value (cal g^{-1}). Commercial butter sample had the highest hardness and stickiness values among all the samples produced.

Furthermore, crystal size was the highest in commercial butter. Consumer decision tests of oleogels displayed that, almost 50% of participants indicated that could buy oleogels.

On the other hand, 25% of participants decided "definitely not buy" hazelnut oil beeswax oleogels. Regarding hedonic test results, while commercial butter had the highest scores from appearance, odor, and flavor; it got lowest from spreadability. On the contrary, commercial breakfast margarine had the highest scores from all hedonic test parameters.

Margarines were produced with soybean oil oleogels formed by sunflower wax, rice bran wax, and candelilla wax at different concentrations ranging between 1% and 6%. Textural properties, melting point, and solid fat content of samples were determined, and the results were compared to those of commercial margarine. Phase separation was observed in the margarines produced by candelilla. The melting points of commercial spreadable products and commercial margarine samples varied between 25 and 40°C. On the other hand, the melting points of sunflower wax oleogels were found to be between 30 and 60°C. As expected, the increasing gelator concentration increased the melting points of oleogel margarines. The oleogels produced with oleogelator content varying from 1% to 6% are stated to have a substantial fat content value between 1% and 8% at 35°C. Similarly, it was reported that the solid fat content of oleogels increased at 35°C depending on the oleogelator concentration, but not affected by temperature changes. The hardness value of oleogel margarine containing 6% sunflower wax was found to be higher than that of the oleogel margarine containing the same amount of rice bran wax. Similar to the melting points, the hardness value also increased with the increasing gelator amount. The hardness value of margarine produced from oleogel containing 2% sunflower wax was found to be similar to commercially spreadable products. The hardness value of margarine produced from oleogel containing 10% sunflower wax was reported to be similar to the commercial margarine sample. In the study, it was also stated that the hardness values of the spreadable samples used as the control group were lower than the hardness values of the commercial margarines (Hwang et al., 2013).

Hwang et al. (2014), manufactured 12 different oleogels using 12 different vegetable oils and sunflower wax as gelator and investigated the possibility of an alternative to solid fat in margarine. The

minimum gelling ability of sunflower wax found to be between 0.3% and 1.0% (w/w). Organogels were fabricated by different concentrations of sunflower wax (3%, 5%, and 7%). Textural properties, fatty acid composition, polar compounds, thermal properties, and drop point values were examined. All vegetable oil organogels added to margarine resulted in increasing the firmness of the margarines. The margarine prepared from organogels containing 3% sunflower were found to be firmer than spreadable margarine, whereas margarine made from 7% sunflower wax were softer than commercial stick margarine.

Regarding the dropping points, margarine containing 5% sunflower wax had higher dropping points than spreads and commercial margarine. The firmness value of the margarine containing organogels was found to be higher than that of commercially spread margarine, but lower than commercial margarine. The highest value regarding polar composition was in the pumpkin seed oil. In general, there is no linear relationship between the fatty acid composition and the firmness of the organogels and the margarine.

Phytosterols usually can be found in the cell membranes of plants, and their chemical structure is very similar to cholesterol in the human body. Because they exist in plant cells, they are called plant sterols or stanol esters, especially campesterol, sitosterol, and stigmasterol commonly in the human diet. Additionally, they are able to compete with the absorption of cholesterol when they are digested in the human body. Because of this, the cholesterol level in blood can decrease significantly by interrupting the absorption of cholesterol (Katan et al., 2003; Abumweis et al., 2008). The common source of phytosterols is vegetable oils and margarine because they are more and more widely added to all kinds of processed foods and the intake of phytosterols increases due to the development of health consciousness (Weihrauch and Gardner, 1978). Besides, grains or cereals are also a major source of phytosterols because they provide a high amount of phytosterols (Valsta et al., 2004).

In food industries, the structure and crystallization of lipid can be modified by phytosterols to alter lipid structures to the specific desirable physicochemical properties (Wassell et al., 2010). Many physical properties such as melting point and uniformity in fats can be modified by phytosterols due to the alternation of covalent bonds, ionic bonds, hydrogen bonds, and Van Der Waals force in lipid compounds to cause the higher consistency of the continuous crystal conformation in the reconstruction of fats or oils (Pernetti et al., 2007).

The lipid matrices in cocoa butter can be modified by the addition of fully hydrogenated soybean oil with the low content (Ribeiro et al., 2013). Refined palm oils and refined canola oils were mixed well with five different ratios at 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100 (w/w). Afterward, they all are blended with two groups: one was 10% (w/w) dispersed phytosterols, and another was 10% (w/w) dispersed phytosterols and 5% (w/w) fully hydrogenated soybean oil. As a result, the mixture of the palm oil and canola oils with 10% of phytosterols and 5% soybean oils can change the physical properties and crystallization behavior in the lipid. The polymorphism of the fatty systems was modified by phytosterols resulting in the rising β -form to β' -form simultaneously. Phytosterols with lower palm oil content also provide more stable consistency and relationship with temperatures. Besides, the analysis of the fatty acid composition indicated that the control mixture and the mixture with soybean oil provide higher polyunsaturated fatty acids content and lower saturated fatty acids content. In summary, the mixtures of palm/canola oils at ratio 60:40 and 40:60 with or without phytosterols and soybean oil can contribute great spreadability in certain food products such as spreadable margarine and butter. The rest of the mixtures can be utilized for the products that require less oil exudation at room temperature (Godoi et al., 2018).

5.2 Chocolate and fillings

Filled chocolates, which are considered as luxury products, consist of two main materials, and these are a hard chocolate shell and soft filling. One of the most common filling components is hazelnut filling, which contains a fat phase, hazelnut, and sugar. In fat phase, cocoa butter, palm oil, hazelnut oil, and other vegetable fats are commonly used. The high amount of saturated fatty acid in palm oil is a known fact. Due to such adverse property, many studies focused on the replacement of palm oil and its fractions in foods.

Doan et al. (2016) investigated the possible usage of beeswax oleogels as a replacement of palm oil in hazelnut fillings. For this purpose, they produced oleogels with different concentrations of beeswax (1.5, 2, 2.5, 3, and 3.5) and mixed with palm oil at different replacement amounts (17%, 33%, and 50%). Rheological properties, solid fat content, thermal behavior studies, microstructure, and oil loss analysis were performed, and the results were compared to those of reference. With the increase in heat, all samples displayed a linear decrease in solid fat content values. At 5°C, the ratio level of replacement was significantly effective on the solid fat content. Solid fat content values decreased with the increasing amount of oleogels. The amount of solid fat was found to be less than 2% at body temperature. The platelet crystals, which was able to entrap liquid oil, with the length of 15–30 nm were observed in beeswax-based oleogels. In shape and size, any changes were observed when the temperature increased from 5°C to 20°C. The density and order of the 17% beeswax oleogel sample was found to be higher than those of 33% and 50% at the same wax concentration (2.5%). The increasing replacement ratio of palm oil (PO) with Beeswax (BW)-oleogels lowered the shift of the crystallization peak. The reference sample had a higher peak melting temperature (33.6°C) compared to the sample containing 3% beeswax, which was 50% replacement. The increase in the beeswax amount caused a higher melting temperature and the same palm oil replacement. Regarding rheological properties, G' (elastic modulus) was found to be higher than G'' (viscous modulus) at all sample analyzed, and all G' values displayed an increasing trend. The complex modulus of 2.5% beeswax samples was the highest among all samples including reference. On the contrary, a tangent delta value of the same sample was the lowest. The higher amount of palm oil tended to decrease the complex modulus. No significant difference was observed in G' of the same replacement ratio of palm oil at 5°C. The time-dependent behavior of the same-replacement-ratio samples showed no significant difference. The level of dripped oil from the gels was so fast at the first day at 20°C. After 2 days, because of the slow crystallization behavior of palm oil in the matrix, oil loss decreased. The beeswax-based oleogels were found to be more effective on crystallization by pushing the process to higher temperatures, whereas reference showed a similar effect during cooling. Furthermore, the increasing amount of beeswax accelerated crystallization.

Fayaz et al. (2017) studied beeswax, propolis wax, and monoglyceride oleogels as a substitute of palm in chocolate spreads. The gelator amount in oils was 5%, and chocolate spreads were fabricated with a combination of palm oil and oleogels (1:1). Microstructure, oil-binding capacity, and mechanical properties were studied. Although the palm oil crystals exhibited spherulitic crystal, oleogels had platelet-like structure. In monoglyceride palm oil complex, both platelet-like and spherulitic crystals were monitored.

On the contrary, in wax oleogels palm oil mixture, platelet-like crystals were dominant. The results showed that the strong reciprocal interactions between monoglyceride and palm oil crystal resulted in a strong three-dimensional network. In rheological results, both storage and loss modulus values were

found to be higher in monoglyceride samples than those of wax samples. Although the morphological structure of wax oleogels was similar, rheological parameters of beeswax-based oleogels were found to be higher than those of propolis wax. Phenolic compounds present in propolis wax affected the formation of the crystalline network negatively, and thus such samples exhibited weaker gel strength. Oil-binding capacity of beeswax-based and monoglyceride-based samples were not significantly different. Propolis wax-based samples, on the other hand, had the lowest oil-binding capacity among all samples analyzed. Sugar in the formulation had the high number of peaks in XRD patterns of chocolate samples containing oleogels. Monoglyceride containing chocolates was found to be harder than wax-based oleogels containing samples. Although the firmness value of monoglyceride-based oleogel containing chocolate samples gradually decreased, in the samples contained monoglyceride oleogel decreasing was slight during storage at 20°C. Such changes could be attributed to the hydrogen bonds of monoglyceride-based oleogels. A fast decrease was observed in the G' value of monoglyceride, beeswax, and propolis wax-based oleogel containing chocolates at the critical stress values, which were 1419, 790.6 and 654.1 Pa, respectively. The monoglyceride-based chocolate samples had a stronger structure than that of beeswax and propolis wax samples. As expected, G' values of all samples were higher than G'' values, which indicated a gel-like structure.

In another study, [Wendt et al. \(2017\)](#) performed a study on the feasibility of β -sitosterol + γ -oryzanol-structured organogels in filled chocolates as a migration barrier. Thermal properties of these chocolates were measured during 24 weeks at different storage temperatures of 10, 18, and 28°C. Formation of chocolate samples had three layers, which were chocolate as the top layer, gel as a middle layer, and nougat as the bottom layer. According to layer formation, three different samples were fabricated; those were chocolate + gel + nougat (i), chocogel + nougat (2.5% gel) (ii), and chocolate + nougatgel (2.5% gel) (iii). Furthermore, the oleogel amount in the samples was given as letters (A–E). The samples held at 10°C did not display significant changes, whereas samples at 23°C showed the highest oil migration during storage. The best oil migration result was observed in sample D (iii), which was containing oleogel of 2.5% (w/w) in the structured nougat layer at 18°C. All oleogel samples and the reference sample displayed a small amount of migrated oil at 18°C storage. The oil migration levels of three-layer systems increased initially but stabilized slowly. Effectivity of suppressing oil migration was related to higher incorporation levels of oleogel. The oil migration levels were found to be related to oleogel inclusion level. Overall, the addition of oleogels into the composition was found to be effective for preventing oil migration. It was stated that for the best migration-preventing effect, gelators should be added directly into the chocolate layer.

5.3 Usage of the oleogels as delivering material

As known, oleogelation is the process in which the liquid oil is entrapped three-dimensional network. This entrapping ability of the oleogels paves the way for the idea of delivering important functional compounds such as bioactive molecules, antioxidant, and antimicrobial agents like chlorine ([Lee et al., 2015, 2016](#)).

One of the studies related to this topic was conducted by [Martins et al. \(2017\)](#). They investigated possible usage of β -carotene fortified oleogels prepared by beeswax. The rheological properties, color values, oil-binding capacity, thermal properties, oxidative stability, and microstructure of samples were evaluated. High oleic sunflower oil as oil phase and beeswax (2%, 4%, 6%, and 8% (w/w)) as oleogelator were used. The amount of β -carotene was 0.01% in all fortified samples. In the polarized light

micrographs of regular and fortified oleogel samples, there were no differences observed. The crystal structure of samples containing a lower amount (<4%) of beeswax was easy to identify. Full solubilization of β -carotene was monitored by polarized microscopy, and no supersaturation was observed.

The increase of beeswax amount in the composition resulted in an increase of the crystallization temperature and melting temperature. The presence of β -carotene was not effective for the thermal properties at higher gelator concentrations.

Regarding nonthermal oscillatory tests, G'' values were found to be higher than G' values before gelation started. After gelation, G' values became higher than G'' , which was the indication of the formation of a three-dimensional network. A linear increase was observed in the viscoelastic properties of samples, due to the addition of β -carotene, which made the matrix more homogenous. Furthermore, β -carotene decreased the heterogeneous effects caused by beeswax. Regarding mechanical properties, as expected elasticity was found to be higher than viscosity in all samples analyzed.

Interestingly, the addition of β -carotene increased the G' values in the samples containing the same amount of beeswax. The oil-binding capacity was found to be higher in oleogel samples containing carotene. With the increasing of wax concentration, oxidative stability increased. Regarding color values, L^* , a^* , and b^* values were not affected by the concentration of wax in β -carotene containing samples. The results of the study suggested that the oleogels could be used as carrier materials for bioactive compounds.

Bioactivity of phytosterol crystals, which have the ability to reduce LDL cholesterol, depends on its size. Moschakis et al. (2017) tried to increase the bioactivity of phytosterols by incorporating them into emulsions with γ -oryzanol. For this aim, they prepared oil phase using sunflower oil and different concentrations of phytosterol and γ -oryzanol. Then, water–oil emulsions were prepared. Model yogurts were prepared using 2%–4% organogel-emulsion as a fat source. Microstructure, thermal properties, droplet size measurements, and rheological behavior of yogurts were examined. When the concentration of phytosterol reached 3%, crystal formation started. The size of crystals of phytosterol was found to be larger than γ -oryzanol. If the ratio between phytosterol and γ -oryzanol was close, microstructure could be better. There were no crystals observed even at a phytosterol concentration of 15%, once the crystals formed emulsions exhibited pseudoplastic behavior. At the first stages of the acidification process, storage modulus was found to be low and tangent delta was high. As soon as acidification started, G' value increased immediately, and the tangent value decreased. The weakest gel structure in yogurt was found in the sample and had an equimolar ratio of γ -oryzanol to phytosterols (60:40). To sum, organogelation approach was helpful to dissolve phytosterol in oil and increase bioactivity. This study paves the way for producing new dairy products that could contain a high amount of phytosterol.

Yilmaz et al. (2015) investigated physicochemical properties and consumer preference of fish organogels flavored with lemon and strawberry. Organogels were fabricated using fish oil, beeswax (5%), and flavors (0%–5%). Results showed that crystal formation time of oleogels was 625 min. The crystal formation times of organogels samples were not related to the concentration of wax. The oil-binding capacity of all samples was found to be above 99%. The addition of flavor did not affect the solid fat content. There were no differences between the crystallization and melting values of gels. It was reported that all organogels samples were found to be stable for 90 days of storage. The maximum firmness value of fish oil organogels was found to be higher than that of flavored ones.

Similarly, the maximum stickiness value was obtained from fish oil organogels. During storage, all color parameters (L^* , a^* , b^*) of fish oil oleogels were found to be higher than those of lemon- and strawberry-flavored organogels.

On the other hand, no significant differences between color values of flavored organogels samples were obtained. At the beginning of storage peroxide value was close, whereas there were differences at the end of storage. Regarding sensory evaluation, the best grades in appearance were fish oil organogels: in smell, strawberry-flavored organogels, in taste both flavored samples, and in spreadability fish oil organogels. In the overall evaluation, the flavored organogels were found to be more preferred.

Kasparaviciene and his colleagues (2018) optimized colloidal silica, paraffin oil, aerosil and essential oil of thyme and structured oils by making oleogel. The analysis conducted with Gas Chromatography – Flame Ionization Detector (GC-FID) showed that containing oleogel treatment declined thymol concentration and carvacrol concentration. The texture analysis indicated that increasing gelator and colloidal silica concentration increased all texture parameters of the sample. It is determined that mechanical properties of oleogel samples were developed by gelator proportion. The results showed that colloidal silica was the most important material because of its gelation ability. The antimicrobial analysis conducted on *Candida albicans* indicated that thymol containing oleogel showed minimum inhibition on *Candida albicans* colony.

6. Conclusion

Solid fats play an important role in the manufacture of food products that have desirable quality properties by consumers. Different methods were used for producing solid fats including hydrogenation, interesterification, and fractionation. These solidification methods cause an increase in the amount of saturated and trans-fatty acids, which can trigger many diseases such as obesity, diabetes, and cardiovascular problems. The increasing demand of people who try to adopt healthy lifestyle forced both manufacturers and researchers to find new ways to reduce these unhealthy compounds in foods. Oleogels, which promise not only a lower amount of saturated and trans-fatty acids but also a higher amount of unsaturated fatty acids, come into prominence recently. Numerous studies were published on the usage of oleogels in different foods such as dairy, bakery, and meat products. The results exhibited that foods containing oleogels had almost similar properties with foods containing commercial solid fat regarding textural, rheological, thermal, and sensorial properties. However, some of the studies pointed out that some properties could not be achieved by using oleogel instead of traditional solid fat. Sensorial analysis indicated that using oleogels can cause some defects in the food regarding consumer perception. One of the disadvantages of using oleogels in food formulations is the smell of gelators. However, few studies suggested that using aroma compounds such as butter and various fruit aroma could repress the unwanted odor. Almost all physicochemical properties of oleogel-based foods have been investigated, but the digestion of these foods was not examined clearly. The promising approach in studying of oleogels could be monitoring their metabolically behavior in vitro and in vivo. Moreover, protein-based oleogels are promising tools that can provide both lower amount of saturated fatty acids and a higher amount of proteins. Consequently, although the oleogels can be used in a wide range of food products with promising results, more studies should be performed to enlighten every aspect of this topic.

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References

- Abumweis, S., Barake, R., Jones, P., 2008. Plant sterols/stanols as cholesterol lowering agents: a meta-analysis of randomized controlled trials. *Food and Nutrition Research* 52 (1), 1811.
- Asuming-Bediako, N., Jaspal, M.H., Hallett, K., Bayntun, J., Baker, A., Sheard, P.R., 2014. Effects of replacing pork backfat with emulsified vegetable oil on fatty acid composition and quality of UK-style sausages. *Meat Science* 96 (1), 187–194.
- Barbut, S., Wood, J., Marangoni, A., 2016. Quality effects of using organogels in breakfast sausage. *Meat Science* 122, 84–89.
- Barbut, S., Wood, J., Marangoni, A.G., 2016. Effects of organogel hardness and formulation on acceptance of frankfurters. *Journal of Food Science* 81 (9), C2183–C2188.
- Bemer, H.L., Limbaugh, M., Cramer, E.D., Harper, W.J., Maleky, F., 2016. Vegetable organogels incorporation in cream cheese products. *Food Research International* 85, 67–75.
- Blake, A.I., Marangoni, A.G., 2015. Factors affecting the rheological properties of a structured cellular solid used as a fat mimetic. *Food Research International* 74, 284–293.
- Bloukas, J.G., Paneras, E.D., Fournitzis, G.C., 1997. Effect of replacing pork back fat with olive oil on processing and quality characteristics of fermented sausages. *Meat Science* 45 (2), 133–144.
- Bolumar, T., LaPena, D., Skibsted, L.H., Orlien, V., 2016. Rosemary and oxygen scavenger in active packaging for prevention of high-pressure induced lipid oxidation in pork patties. *Food Packaging and Shelf Life* 7, 26–33.
- Calligaris, S., Manzocco, L., Valoppi, F., Nicoli, M.C., 2013. Effect of palm oil replacement with monoglyceride organogel and hydrogel on sweet bread properties. *Food Research International* 51 (2), 596–602.
- Chaves, K.F., Barrera-Arellano, D., Ribeiro, A.P.B., 2017. Potential application of lipid organogels for food industry. *Food Research International* 105, 863–872. March 2018.
- da Silva, S.L., Amaral, J.T., Ribeiro, M., Sebastião, E.E., Vargas, C., de Lima Franzen, F., Campagnol, P.C.B., 2019. Fat replacement by oleogel rich in oleic acid and its impact on the technological, nutritional, oxidative, and sensory properties of Bologna-type sausages. *Meat Science* 149, 141–148.
- De Vogli, R., Kouvonen, A., Gimeno, D., 2014. The influence of market deregulation on fast food consumption and body mass index: a cross-national time series analysis. *Bulletin of the World Health Organization* 92, 99–107A.
- Doan, C.D., Patel, A.R., Tavernier, I., De Clercq, N., Van Raemdonck, K., Van de Walle, Delbaere, C., Dewettinck, K., 2016. The feasibility of wax-based oleogel as a potential co-structurant with palm oil in low-saturated fat confectionery fillings. *European journal of lipid science and technology* 118 (12), 1903–1914.
- Doan, C.D., Tavernier, I., Danthine, S., Rimaux, T., Dewettinck, K., 2018. Physical compatibility between wax esters and triglycerides in hybrid shortenings and margarines prepared in rice bran oil. *Journal of the Science of Food and Agriculture* 98 (3), 1042–1051.
- Enser, M., Hallett, K., Hewitt, B., Fursey, G.A.J., Wood, J.D., 1996. Fatty acid content and composition of English beef, lamb and pork at retail. *Meat Science* 42 (4), 443–456.
- Fayaz, G., Goli, S.A.H., Kadivar, M., Valoppi, F., Barba, L., Calligaris, S., Nicoli, M.C., 2017. Potential application of pomegranate seed oil oleogels based on monoglycerides, beeswax and propolis wax as partial substitutes of palm oil in functional chocolate spread. *LWT-Food Science and Technology* 86, 523–529.
- Felisberto, M.H.F., Wahanik, A.L., Gomes-Ruffi, C.R., Clerici, M.T.P.S., Chang, Y.K., Steel, C.J., 2015. Use of chia (*Salvia hispanica* L.) mucilage gel to reduce fat in pound cakes. *LWT-Food Science and Technology* 63 (2), 1049–1055.
- Gebhardt, S., Lemar, L., Haytowitz, D., Pehrsson, P., Nickle, M., Showell, B., Holden, J., 2008. USDA National Nutrient Database for Standard Reference, Release, vol. 21. United States Department of Agriculture Agricultural Research Service.

- Godoi, K.R.R., Basso, R.C., Buscato, M.H.M., Cardoso, L.P., Kieckbusch, T.G., Ribeiro, A.P.B., 2018. Dispersed free phytosterols as structuring agents in lipid systems with reduced saturated fat. *Grasas Y Aceites* 68 (4), 217.
- Gök, V., Akkaya, L., Obuz, E., Bulut, S., 2011. Effect of ground poppy seed as a fat replacer on meat burgers. *Meat Science* 89 (4), 400–404.
- Gómez-Estaca, J., Herrero, A.M., Herranz, B., Álvarez, M.D., Jiménez-Colmenero, F., Cofrades, S., 2019. Characterization of ethyl cellulose and beeswax oleogels and their suitability as fat replacers in healthier lipid pâtés development. *Food Hydrocolloids* 87, 960–969.
- Hughes, N.E., Marangoni, A.G., Wright, A.J., Rogers, M.A., Rush, J.W., 2009. Potential food applications of edible oil organogels. *Trends in Food Science & Technology* 20 (10), 470–480.
- Hwang, H.S., Singh, M., Bakota, E.L., Winkler-Moser, J.K., Kim, S., Liu, S.X., 2013. Margarine from organogels of plant wax and soybean oil. *Journal of the American Oil Chemists' Society* 90 (11), 1705–1712.
- Hwang, H.S., Singh, M., Winkler-Moser, J.K., Bakota, E.L., Liu, S.X., 2014. Preparation of margarines from organogels of sunflower wax and vegetable oils. *Journal of Food Science* 79 (10), C1926–C1932.
- Hwang, H.S., Singh, M., Lee, S., 2016. Properties of cookies made with natural wax–vegetable oil organogels. *Journal of Food Science* 81 (5), C1045–C1054.
- Idris, N.A., Dian, N.L.H.M., 2005. Interesterified palm products as alternatives to hydrogenation. *Asia Pacific Journal of Clinical Nutrition* 14 (4), 396.
- Jang, A., Bae, W., Hwang, H.S., Lee, H.G., Lee, S., 2015. Evaluation of canola oil oleogels with candelilla wax as an alternative to shortening in baked goods. *Food Chemistry* 187, 525–529.
- Joint, F.A.O., 2010. *Fats and Fatty Acids in Human Nutrition*. Report of an expert consultation, 10–14 November 2008, Geneva.
- Kasparaviciene, G., Kalveniene, Z., Pavilonis, A., Marksiene, R., Dauksiene, J., Bernatoniene, J., 2018. Formulation and characterization of potential antifungal oleogel with essential oil of thyme. *Evidence-Based Complementary and Alternative Medicine* 2018.
- Katan, M.B., Grundy, S.M., Jones, P., Law, M., Miettinen, T., Paoletti, R., Participants, S.W., August 2003. Efficacy and safety of plant stanols and sterols in the management of blood cholesterol levels. In: *Mayo Clinic Proceedings*, vol. 78 (8). Elsevier, pp. 965–978.
- Kaushik, I., Jain, A., Grewal, R.B., et al., 2017. Organogelation: its food application. *MOJ Food Process Technology* 4 (2), 66–72.
- Kayaardi, S., Gök, V., 2003. Effect of replacing beef fat with olive oil on quality characteristics of Turkish soudjouk (sucuk). *Meat Science* 66, 249–257.
- Kim, J.Y., Lim, J., Lee, J., Hwang, H.S., Lee, S., 2017. Utilization of oleogels as a replacement for solid fat in aerated baked goods: physicochemical, rheological, and tomographic characterization. *Journal of Food Science* 82 (2), 445–452.
- Kouzounis, D., Lazaridou, A., Katsanidis, E., 2017. Partial replacement of animal fat by oleogels structured with monoglycerides and phytosterols in frankfurter sausages. *Meat Science* 130, 38–46.
- Lee, C.C., Chen, J., Frank, J.F., 2015. Role of cellulose and colanic acid in attachment of Shiga toxin–producing *Escherichia coli* to lettuce and spinach in different water hardness environments. *Journal of Food Protection* 78 (8), 1461–1466.
- Lee, C.C., Chen, J., Frank, J.F., 2016. Influence of extracellular cellulose and colanic acid production on the survival of shiga toxin–producing *Escherichia coli* on spinach and lettuce after chlorine treatment. *Journal of Food Protection* 79 (4), 666–671.
- Lim, J., Jeong, S., Lee, S., 2017a. Evaluation of soybean oil-carnauba wax oleogels as an alternative to high saturated fat frying media for instant fried noodles. *LWT-Food Science and Technology* 84, 788–794.
- Lim, J., Jeong, S., Lee, J., Park, S., Lee, J., Lee, S., 2017b. Effect of shortening replacement with oleogels on the rheological and tomographic characteristics of aerated baked goods. *Journal of the Science of Food and Agriculture* 97 (11), 3727–3732.

- Lupi, F.R., Gabriele, D., Seta, L., Baldino, N., de Cindio, B., 2014. Rheological design of stabilized meat sauces for industrial uses. *European Journal of Lipid Science and Technology* 116 (12), 1734–1744.
- Martins, A.J., Cerqueira, M.A., Cunha, R.L., Vicente, A.A., 2017. Fortified beeswax oleogels: effect of β -carotene on the gel structure and oxidative stability. *Food and Function* 8 (11), 4241–4250.
- Martins, A.J., Vicente, A.A., Cunha, R.L., Cerqueira, M.A., 2018. Edible oleogels: an opportunity for fat replacement in foods. *Food and Function* 9 (2), 758–773.
- McGuire, S., 2016. Scientific report of the 2015 Dietary Guidelines Advisory Committee. Washington, DC: US Departments of Agriculture and Health and Human Services, 2015. *Advances in Nutrition* 7 (1), 202–204.
- Mensink, R.P., Katan, M.B., 1990. Effect of dietary trans fatty acids on high-density and low-density lipoprotein cholesterol levels in healthy subjects. *New England Journal of Medicine* 323 (7), 439–445.
- Mert, B., Demirkesen, I., 2016a. Evaluation of highly unsaturated oleogels as shortening replacer in a short dough product. *LWT-Food Science and Technology* 68, 477–484.
- Mert, B., Demirkesen, I., 2016b. Reducing saturated fat with oleogel/shortening blends in a baked product. *Food Chemistry* 199, 809–816.
- Moghtadaei, M., Soltanizadeh, N., Goli, S.A.H., 2018. Production of sesame oil oleogels based on beeswax and application as partial substitutes of animal fat in beef burger. *Food Research International* 108, 368–377.
- Moriano, M.E., Alamprese, C., 2017. Organogels as novel ingredients for low saturated fat ice creams. *LWT-Food Science and Technology* 86, 371–376.
- Moschakis, T., Dergiade, I., Lazaridou, A., Biliaderis, C.G., Katsanidis, E., 2017. Modulating the physical state and functionality of phytosterols by emulsification and organogel formation: application in a model yogurt system. *Journal of Functional Foods* 33, 386–395.
- Mozaffarian, D., Katan, M.B., Ascherio, A., Stampfer, M.J., Willett, W.C., 2006. Trans fatty acids and cardiovascular disease. *New England Journal of Medicine* 354 (15), 1601–1613.
- Öğütçü, M., Yılmaz, E., 2014. Oleogels of virgin olive oil with carnauba wax and monoglyceride as spreadable products. *Grasas Y Aceites* 65 (3), 040.
- Oh, I.K., Lee, S., 2018. Utilization of foam structured hydroxypropyl methylcellulose for oleogels and their application as a solid fat replacer in muffins. *Food Hydrocolloids* 77, 796–802.
- Oh, I.K., Amoah, C., Lim, J., Jeong, S., Lee, S., 2017. Assessing the effectiveness of wax-based sunflower oil oleogels in cakes as a shortening replacer. *LWT-Food Science and Technology* 86, 430–437.
- Ospina-E, J.C., Sierra-C, A., Ochoa, O., Pérez-Álvarez, J.A., Fernández-López, J., 2012. Substitution of saturated fat in processed meat products: a review. *Critical Reviews in Food Science and Nutrition* 52 (2), 113–122.
- Öğütçü, M., Arifoğlu, N., Yılmaz, E., 2015. Preparation and characterization of virgin olive oil-beeswax oleogel emulsion products. *Journal of the American Oil Chemists' Society* 92 (4), 459–471.
- Palla, C., Giacomozzi, A., Genovese, D.B., Carrín, M.E., 2017. Multi-objective optimization of high oleic sunflower oil and monoglycerides oleogels: searching for rheological and textural properties similar to margarine. *Food Structure* 12, 1–14.
- Panagiotopoulou, E., Moschakis, T., Katsanidis, E., 2016. Sunflower oil organogels and organogel-in-water emulsions (part II): implementation in frankfurter sausages. *LWT-Food Science and Technology* 73, 351–356.
- Pappa, I.C., Bloukas, J.G., Arvanitoyannis, I.S., 2000. Optimization of salt, olive oil and pectin level for low-fat frankfurters produced by replacing pork back fat with olive oil. *Meat Science* 56 (1), 81–88.
- Park, C., Bemer, H.L., Maleky, F., 2018. Oxidative stability of rice bran wax oleogels and an oleogel cream cheese product. *Journal of the American Oil Chemists' Society* 95 (10), 1267–1275.
- Pehlivanoglu, H., Demirci, M., Toker, O.S., 2017. Rheological properties of wax oleogels rich in high oleic acid. *International Journal of Food Properties* 20 (Suppl. 3), S2856–S2867.
- Pehlivanoglu, H., Ozulku, G., Yildirim, R.M., Demirci, M., Toker, O.S., Sagdic, O., 2018. Investigating the usage of unsaturated fatty acid-rich and low-calorie oleogels as a shortening mimetic in cake. *Journal of Food Processing and Preservation* e13621.

- Pehlivanoglu, H., Demirci, M., Toker, O.S., Konar, N., Karasu, S., Sagdic, O., 2018. Oleogels, a promising structured oil for decreasing saturated fatty acid concentrations: production and food-based applications. *Critical Reviews in Food Science and Nutrition* 58 (8), 1330–1341.
- Pernetti, M., van Malssen, K.F., Flöter, E., Bot, A., 2007. Structuring of edible oils by alternatives to crystalline fat. *Current Opinion in Colloid and Interface Science* 12 (4–5), 221–231.
- Ribeiro, A.P.B., Basso, R.C., dos Santos, A.O., Andrade, G.C., Cardoso, L.P., Kieckbusch, T.G., 2013. Hardfats as crystallization modifiers of cocoa butter. *European Journal of Lipid Science and Technology* 115 (12), 1462–1473.
- Rogers, M.A., 2009. Novel structuring strategies for unsaturated fats—Meeting the zero-trans, zero-saturated fat challenge: a review. *Food Research International* 42 (7), 747–753.
- Schaink, H.M., Van Malssen, K.F., Morgado-Alves, S., Kalnin, D., Van der Linden, E., 2007. Crystal network for edible oil organogels: possibilities and limitations of the fatty acid and fatty alcohol systems. *Food Research International* 40 (9), 1185–1193.
- Singh, A., Auzanneau, F.I., Rogers, M.A., 2017. Advances in edible oleogel technologies—A decade in review. *Food Research International* 97, 307–317.
- Toro-Vazquez, J.F., Morales-Rueda, J.A., Dibildox-Alvarado, E., Charó-Alonso, M., Alonzo-Macias, M., González-Chávez, M.M., 2007. Thermal and textural properties of organogels developed by candelilla wax in safflower oil. *Journal of the American Oil Chemists' Society* 84 (11), 989–1000.
- Utrilla, M.C., Ruiz, A.G., Soriano, A., 2014. Effect of partial replacement of pork meat with an olive oil organogel on the physicochemical and sensory quality of dry-ripened venison sausages. *Meat Science* 97 (4), 575–582.
- Valsta, L.M., Lemström, A., Ovaskainen, M.L., Lampi, A.M., Toivo, J., Korhonen, T., Piironen, V., 2004. Estimation of plant sterol and cholesterol intake in Finland: quality of new values and their effect on intake. *British Journal of Nutrition* 92 (4), 671–678.
- Wang, F.C., Gravelle, A.J., Blake, A.I., Marangoni, A.G., 2016. Novel trans fat replacement strategies. *Current Opinion in Food Science* 7, 27–34.
- Wassell, P., Bonwick, G., Smith, C.J., Almiron-Roig, E., Young, N.W., 2010. Towards a multidisciplinary approach to structuring in reduced saturated fat-based systems—a review. *International Journal of Food Science and Technology* 45 (4), 642–655.
- Weihrauch, J.L., Gardner, J.M., 1978. Sterol content of foods of plant origin. *Journal of the American Dietetic Association* 73 (1), 39–47.
- Wendt, A., Abraham, K., Wernecke, C., Pfeiffer, J., Flöter, E., 2017. Application of β -sitosterol+ γ -oryzanol-structured organogel as migration barrier in filled chocolate products. *Journal of the American Oil Chemists' Society* 94 (9), 1131–1140.
- Wolfer, T.L., Acevedo, N.C., Prusa, K.J., Sebranek, J.G., Tarté, R., 2018. Replacement of pork fat in frankfurter-type sausages by soybean oil oleogels structured with rice bran wax. *Meat Science* 145, 352–362.
- Youssef, M.K., Barbut, S., 2011. Fat reduction in comminuted meat products-effects of beef fat, regular and pre-emulsified canola oil. *Meat Science* 87 (4), 356–360.
- Yılmaz, E., Ögütçü, M., 2014. Comparative analysis of olive oil organogels containing beeswax and sunflower wax with breakfast margarine. *Journal of Food Science* 79 (9), E1732–E1738.
- Yılmaz, E., Ögütçü, M., 2015. The texture, sensory properties and stability of cookies prepared with wax oleogels. *Food and Function* 6 (4), 1194–1204.
- Yılmaz, E., Ögütçü, M., 2015. Oleogels as spreadable fat and butter alternatives: sensory description and consumer perception. *RSC Advances* 5 (62), 50259–50267.
- Yılmaz, E., Ögütçü, M., Arifoglu, N., 2015. Assessment of thermal and textural characteristics and consumer preferences of lemon and strawberry flavored fish oil organogels. *Journal of Oleo Science* 64 (10), 1049–1056.

- Zetzl, A.K., Marangoni, A.G., Barbut, S., 2012. Mechanical properties of ethylcellulose oleogels and their potential for saturated fat reduction in frankfurters. *Food & function* 3 (3), 327–337.
- Zulim Botega, D.C., Marangoni, A.G., Smith, A.K., Goff, H.D., 2013. The potential application of rice bran wax oleogel to replace solid fat and enhance unsaturated fat content in ice cream. *Journal of Food Science* 78 (9), C1334–C1339.
- Zulim Botega, D.C., Marangoni, A.G., Smith, A.K., Goff, H.D., 2013. Development of formulations and processes to incorporate wax oleogels in ice cream. *Journal of Food Science* 78 (12), C1845–C1851.

Further reading

- Rogers, M.A., Wright, A.J., Marangoni, A.G., 2009. Oil organogels: the fat of the future? *Soft Matter* 5 (8), 1594–1596.

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