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Ilkem Demirkesen & Behic Mert

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REVIEW

Recent developments of oleogel utilizations in bakery products

Ilkem Demirkesen[a] and Behic Mert[b]

[a]Department of Animal Health, Food and Feed Research, General Directorate of Agricultural Research and Policies, Ministry of Agriculture and Forestry, Ankara, Turkey; [b]Department of Food Engineering, Middle East Technical University, Ankara, Turkey

ABSTRACT
Available evidence from clinical trials suggests the replacement of saturated fatty acids with polyunsaturated fatty acids as well as with essential fatty acids to reduce the risk of coronary heart disease. Thus, the importance of limiting of saturated fatty acid intake as well as the removal of trans-fatty acids from the diet have also emphasized. Conversely, recent studies have questioned the simple explanation of the relationship of dietary saturated fats and of individual saturated fatty acids to cardiovascular disease. Although, controversies continue to exist, current recommendations have highlighted that the importance of a critical look at the evaluation of scientific understanding about dietary fats and health. Therefore, manufacturers and scientists have focused on seeking alternative ways to modify or structure liquid oil without the use of saturated and trans-fats and hence to offer the functionality of fats to food products without changing the nutritional profile of liquid oil. However, since shortening as the essential component of bakery products affects dough structure and the desired final product attributes, the replacement of shortening creates a big challenge in bakery problems. The aim of this study was to provide an overview of the functions of shortening in bakery products and of the field of oleogels with special importance on the updates from recent years and their possible applications in bakery products. With the incorporation of oleogels or oleogel/shortening blends, rheological properties of dough/batters as well as physicochemical properties of resulted products may be resembled to those made with shortening. Conversely, the application of this technique had a role on retaining solid-like properties while possesses a healthier fatty acid profile. Very recent study indicated that gradual replacement of shortening with oleogels have potential for partial reduction of saturated fat without chancing physical properties of gluten free aerated products. Thus, the applications of oleogels may also present more alternatives for celiac sufferers' diet.

KEYWORDS
Oleogel; oleogel/shortening blends; shortening; bakery products; shortening replacer

Introduction

Shortening can be classified as the naturally occurring fats that are solid at room temperature. The composition of it can be varied from a natural fat to blends of oils with hard fats to hydrogenated liquid oils to blends of oil containing ingredients such as emulsifiers, antioxidants, metal scavengers, and antispattering agents (O'Brien, 2005). The presence of a large proportion of high-melting triacylglycerols (TAGs) in shortenings forms crystalline structures at room temperature which provides a network and hence limits the lower-melting TAGs (Mattice and Marangoni, 2019).

The main of function of shortening is to tenderize finished products. As an edible solid fat product, it is one of the most critical ingredients in bakery products such as breads, cakes, cookies, and pastries for centuries. Besides, being a solvent for some valuable nutrients, bioactive compounds, and flavor carriers; in bakery products shortening has a key role to cover gluten and starch granules to prevent their adherence to each other. Therefore, it is responsible from the lubrication of gluten particles and the plasticity of the dough that offer air incorporation. It also reduces elastic nature and shrinking of dough during molding. It is also responsible from the entrapment of air during creaming process and the stabilization of air bubbles during mixing, therefore, resulted bakery goods have tender and softer textures with finer porous structures. In addition, shortening provides delicate flavor via creating dough aeration and lubricating effect in the mouth. It also offers a medium for heat transfer during baking. Shortening has also ability to form complexes with amylose and, therefore, it plays the critical role on delaying of the transport of water into the starch granule and also gives a sensation of moistness in the mouth. Consequently, it can prevent staling of products.

Consuming diet high in saturated fats as well as in trans-fats as a well-accepted biomarker for increased risk of cardiovascular and coronary heart diseases has been highlighted in many published reports (Bhupathiraju and Tucker, 2011; Willett, 2012; DiNicolantonio et al., 2016). However, unlike trans-fatty acids, recently some of serious reviews of the evidence have been questioned whether public health recommendations for decreasing of saturated fat intake are appropriate. It has been reported that restriction of saturated

CONTACT Ilkem Demirkesen ilkem.mert@tarimorman.gov.tr; ilkemdemirkesen@gmail.com Department of Animal Health, Food and Feed Research, Ministry of Agriculture and Forestry, General Directorate of Agricultural Research and Policies, Ankara, Turkey.
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fat could lead to their replacement with carbohydrate which could be resulted in increased TAGs with decreased HDL (high-density lipoprotein, good cholesterol) (Volek and Forsythe, 2005; Patel and Dewettinck, 2016). Conversely, available evidence from trials suggests the replacement of saturated fatty acids with polyunsaturated fatty acids (PUFA) as well as with essential fatty acids to reduce the risk of coronary heart disease (Hamley, 2017). Although, debate about restriction of saturated fatty acids is still ongoing; manufacturers and scientists have focused on seeking alternative ways to modify or structure liquid oil without the use of saturated and trans-fats and hence to provide the functionality of fats to food products without changing the nutritional profile of liquid oil (Patel and Dewettinck, 2016). However, the production of bakery products in the lack even in the reduced amount of shortening remains to be a great challenge since shortening affects properties of not only dough/batter but also resulted bakery goods. Solid fat offers much of their functionally and properties due to saturated and trans-fatty acids. The fatty acids which are in the form of TAGs is responsible of creating a fat crystal network and this structures the fat into solid-like material while keeping the liquid oil components of the fat and preventing its exudation (Blake et al., 2018). Recent published studies indicated that drawbacks related to the lack of shortening in bakery goods have been overcome by the application of oleogels, which, therefore, have been receiving attention from both academia and industry.

Organogelation, a novel alternative structuring technique, which is described as structured solid-like materials, in which the entrapment of high amount of liquid oil within a thermoreversible and three dimensional gel network is created. The applications of oleogels have gained considerable interest in food industry. The concept of using a polymer as a structuring agent for gelling vegetable oils in food industry began with the potential use of this molecule as a vegetable oil structuring and food ingredient after the late 1990s (Stortz et al., 2012). Then, the application of oleogels has attracted the attention of scientific community. Now, it is being used for various food products for replacement of solid fats and reduction of saturated fats in ice creams, cooked frankfurters, sausages, cookies, cakes as well as for production of commercial confectionery filling fats (Table 1).

Therefore, the aim of this study was to provide a complete and brief overview of the field of oleogels with special importance on the updates from recent years and their possible applications in bakery products.

The role of shortening in bakery products

As plastic fats, shortening contains of a mixture of solid fat crystals and liquid oil. The solid fat components provide a three-dimensional crystal matrix having a role on holding the liquid portion as well as giving plasticity to dough. Therefore, the consistency, the crystal structure and melting characteristics affect the function of shortening depending upon the application purpose for which they are designed (Reddy and Jeyarani, 2001).

In the bakery industry, different fat mimetics have also been used. Among them, hydrocolloids and modified starch fat substitutes have been extensively used ones. However, it has been stated that it is required to provide body, lubricity, perceived creaminess or smoothness, absorption, and adsorption effects for taste buds or tongue; and possibly cohesiveness, adhesiveness, and waxiness to obtain the perception of fat-like properties from a fat-free food (Jewell and Seaman, 1994). Recently, the applications of oleogels in food have also become popular topic of research. Oleogels should match functionality of shortening as well as match quality characteristics of commercial shortening containing bakery products. Therefore, it is essential to summarize the functional roles of shortening for each bakery products.

The role of shortening in bread

As an aqueous colloidal dispersion, dough/batter generally consists of both hydrophilic (e.g., flour and sugar) and hydrophobic (e.g., fats and shortenings) components. In case of bread-making, the components of dough become crosslinked and form a three-dimensional (3D) structure which traps air bubbles upon baking (Jewell and Seaman, 1994). In a baked product, the interaction between lipids and wheat flour macromolecules known as "shortening effect" can be related to chemical and physical mechanisms. However, the chemical effect having a role in lipid oxidation is considered to be insignificant as compared to physical effects in bread-making. The physical effects of shortening can be summarized as lubrication, sealing, foam formation, involvement of hydrogen, and hydrophobic bonds, delaying of carbon dioxide release and assisting of heat transfer (Pomeranz and Chung, 1978). Shortening is responsible of gas retention in the initial stage of rapid expansion which is so-called "oven spring." Thus, the final loaf volume depends on the permeability of the dough to carbon dioxide in the earliest stages of baking. It has been reported that carbon dioxide releases faster from dough baked without shortening than dough with shortening. In literature, there are several studies indicating the critical role of shortening on entrapment of air bubbles and hence volume of bakery products (Pomeranz and Chung, 1978).

The interactions of shortening with protein as well as with starch also play a critical role in improvement of bread-making. The interaction of shortening with gluten protein improves gas holding ability of dough. In the lack of shortening, gluten and starch particles will adhere to each other giving the sensation of hardness and low volume. The plasticity effect of shortening allows the coating of gluten particles that breaks the continuity of the protein and starch structure and thus the lubrication of gluten particles resulted in a short, tender, and crumbly texture aerated bakery product. Hoseney et al. (1970) postulated that free polar lipids (glycolipids) are bound to gliadin in terms of hydrophilic interactions while they are bound to glutenin by hydrophobic bonds and such simultaneous binding effects may also provide gas-retaining properties to gluten. The interaction of fat with starch has also a critical role on delaying of retrogradation. It has also been reported that

Table 1. An overview of research articles conducted the application of oleogels in food products

Food industry	The application purpose	Wax and oil type	References
Milk-based products/ice cream and cream cheese products	To replace solid fat and to enhance unsaturated fat content in ice cream	Rice bran wax/Sunflower oil	Zulim Botega et al. (2013a)
	To investigate the influence of emulsifiers, waxes, fat concentration, and processing conditions on the application of wax oleogel to replace solid fat content and create optimal fat structure in ice cream	Rice bran wax, candelilla wax, carnauba wax/Sunflower oil	Zulim Botega et al. (2013b)
	To produce oleogel cream cheese products	Rice bran wax, ethylcellulose/ Soybean oil	Bemer et al. (2016)
	To evaluate the use of high unsaturated fats in the production of ice cream as alternative to highly saturated coconut oil	Rice bran wax/Coconut oil	Marín-Suárez et al. (2016)
	To evaluate the effects of oleogelation processing and storage time on the oxidation stability and tocopherol content of vegetable oils and oleogel cream cheese products	Rice bran wax/Soybean oil	Park et al. (2018)
Processed meat products	To evaluate the potential for the use of food grade polymer oleogels in a variety of meat systems	Ethylcellulose/Canola, soybean, and flaxseed oil	Zetzl et al. (2012)
	To observe the relationship between ethylcellulose gel structure and polymer concentration, molecular weight in different oils	Ethylcellulose/Canola, soybean, and flaxseed oil	Zetzl et al. (2014)
Chocolate	To identify the applications of shellac oleogels for a continuous oil phase for preparation of emulsifier-free, structured w/o emulsions (spreads), a replacer for oil-binders in chocolate paste formulations and a shortening alternative for cake preparation	Shellac wax/Rapeseed oil	Patel et al. (2014a)
	To compare three alternative approaches where oil structuring was carried out using wax crystals (shellac), polymer strands (hydrophilic cellulose derivative), and emulsion droplets as structurants in different products (bakery, chocolate, and spreads)	Shellac oleogels (Shellac wax/ Rapeseed oil), HPMC oleogels (Hydroxypropylmethylcellulose/ Sunflower oil), High internal phase emulsion gels (Locust bean gum/ Sunflower oil)	Patel and Dewettinck (2015)
	Development of heat resistance in chocolate using ethylcellulose oleogel	Ethylcellulose	Stortz and Marangoni (2013)/Marangoni and Gregorio (2012)
Spreads	The applications of shellac oleogels as a shortening alternative for spread preparation	Shellac wax/Rapeseed oil	Patel et al. (2014a)
	Development of spreadable products using oleogels	Carnauba wax, monoglyceride/ Olive oil	Öğütcü and Yılmaz (2014)
	To characterize physico-chemical and sensory properties of different oleogels as spreadable fat and butter alternatives	Beeswax, sunflower wax/Hazelnut oil, olive oil	Yılmaz and Öğütcü (2015a)
	To evaluate oleogel as a partial replacement of palm oil in chocolate spread.	Monoglycerides, beeswax, propolis wax/Pomegranate seed oil	Fayaz et al. (2017)
Bakery Products			
Cookie fillings	To evaluate hydroxypropyl methylcellulose and methylcellulose structured oils for their potential in partially and fully substituting shortening in sandwich cookie creams	Hydroxypropylmethylcellulose, methylcellulose/Canola oil	Tanti, Barbut and Marangoni (2016)
Cookie	To evaluate the feasibility of utilization of the organogel technology for cookies	Sunflower wax, rice bran wax, beeswax, candelilla wax/olive oil, flaxseed oil, soybean oil	Hwang et al. (2016)
	To evaluate the oleogels of canola oil with candelilla wax as a shortening replacer in the formulation of cookies	Candelilla wax/Canola oil	Jang et al. (2015)
	To evaluate carnauba wax and candelilla wax oleogels as shortening replacer in cookie formulations.	Carnauba wax, candelilla wax/ Sunflower oil	Mert and Demirkesen (2016a)
	To extent the applications of oleogels to a wider variety of food products by using their blends with shortening and to provide a successful use of oleogels matching quality characteristics of commercial shortening containing cookies	Candelilla wax/Canola oil	Mert and Demirkesen (2016b)
	To evaluate hazelnut oil-beeswax and hazelnut oil-sunflower wax oleogels as a shortening replacer in the formulation of cookies	Beeswax, sunflower wax/Hazelnut oil	Yılmaz and Öğütcü (2015b)
Cake/muffin	To evaluate the influence of monoglycerides oleogels incorporation into muffins	Monoglycerides/Sunflower oil	Giacomozzi et al. (2018)
	To investigate the influence of oleogels as a solid fat replacer on cakes	Carnauba wax/Canola oil	Kim et al. (2017)
	To determine the effects of shortening replacement with the oleogels on the physicochemical properties of the muffins	Candelilla wax/Grape seed oil	Lim et al. (2017)

(*continued*)

Table 1. Continued.

Food industry	The application purpose	Wax and oil type	References
	To determine the effects of different oleogels on the quality attributes of the cakes.	Rice bran, candelilla wax, beeswax oleogels/Sunflower oil	Oh et al. (2017)
	To determine the feasibility of foam-structured Hydroxypropyl methylcellulose as a shortening replacer in muffins	Hydroxypropyl methylcellulose/ Sunflower oil	Oh and Lee (2018).
	The applications of shellac oleogels as a shortening alternative for cake preparation.	Shellac wax/Rapeseed oil	Patel et al. (2014a).
	To determine potential application of edible oleogels as a shortening alternative in cakes	Methyl cellulose, Xanthan gum/ Sunflower oil	Patel et al. (2014b).
	To evaluate the applications of watery and water-free oleogels in formulation of the cakes.	Carnauba wax/Sunflower oil, cotton seed oil	Pehlivanoglu et al. (2018b).
	To evaluate the potential use of oleogel and oleogel/ shortening blends in gluten-free cake formulations	Beeswax/Sunflower seed oil	Demirkesen and Mert (2019).
Bread	To investigate the use of different types of ethylcellulose oleogels against their competency in forming stable shortenings in breads	Ethylcellulose/Soybean oil, palm strearin	Ye et al. (2019).

galactolipid can be distributed in the gluten and, to a limited extent, in the starch. Therefore, most of the galactolipid is in gelatinized starch granules forming a complex and that is seem to be responsible for the improved of freshness in bread baked with glycolipids (Pomeranz, 1973). Beneficial effect of shortening also depends on its moisture retaining effect and, thus, on degree of smoothness and creaminess of dough. It has also been reported that the solid-like elasticity and oil-binding capacity of the shortening maintain the liquid TAGs phase of the fat and prevent seeping into the dough (Co and Marangoni, 2012).

Consequently, shortenings used in bread-making have a wide plastic range at room temperature and a fat fraction which is essential to assure good bread quality should remain solid until the end of fermentation process. Although, the shortening amount in a bread formulation is very low (3% based on flour weight), the presence of sufficient solid fat in the shortening is essential for strengthening of the dough and hence for gas retention during the initial stages of baking. However, it should be noted that the use of too much fat may prevent rising of dough during proofing. It has been stated that for a good baking the bakery shortening must include at least 20% SFC (solid fat content) at room temperature and a minimum of 5% SFC at higher temperature (40 °C) (Rios et al., 2014).

Polymorphism showing different arrangement of molecules on crystallization is often used as an indicator for fat functionality in the food industry. The crystal form of the solidified fat has a major effect upon its textural properties. It affects plasticity of dough depending on the presence of β' crystals. These crystals tend to be smaller in size with needlelike shapes creating strong and plastic shortenings. β' polymorphs provide the most stable crystal form appearing smooth, giving good aeration and excellent creaming properties and (Gunstone, 2001). However, it can convert to β forms which impart a hard, brittle texture and an undesirable grainy and waxy mouthfeel.

The role of shortening in cookies

In case of biscuits and cookies; it is known that large amount of sugars and fats are used while moisture content remain in low proportions. Therefore, shortening applied for the production of cookies must be on solid or semisolid state at room temperature to facilitate handling of the batter during the manufacturing (Rios et al., 2014). Thus, the type of shortening that used in cookie formulations is preferred to possess "plastic" properties which are defined by SFC values. It has been stated that while high SFC values do not have enough oil volume for sufficient aeration, shortening having low SFC values are not capable of holding enough air bubbles until the end of mixing (O'Brien, 2005).

During cookie making, first a white cream is prepared by mixing the sugar, plastic shortening and egg to capture air that are trapped in the liquid phase of the shortening and then flour is added with minimal mixing to obtain minimum gluten development (Rios et al., 2014). Therefore, one of the main function of shortening in cookie dough is to control gluten development by breaking the continuity of the protein and starch structure. The influences of shortening on cookie dough and resulted product depends on shortening level and SFC of the shortening. In the lack of shortening, aqueous phase interacts with the gluten to form cohesive and extensible network. This results in a harder and/or chewier cookie texture. Oppositely, when shortening is present, shortening coats proteins and starch granules, isolating them from the water and limiting the interaction between protein and starch molecules. This leads to a dough with less elastic properties and hence dough does not shrink after lamination. Furthermore, limited gluten network formation is essential for crisp or crumbly texture in cookies (Jacob and Leelavathi, 2007).

The other important role of shortening in cookies is to provide aeration. Plasticity of shortening is important for entrapment and retaining of air during the first creaming process (Jacob and Leelavathi, 2007). This entrapped and stabilized air in cookie dough is responsible from final quality of cookies providing uniform, fine and tender crumb. It has been postulated that the crystals in shortening also play an important role in the stabilization of air bubbles. During mixing stage, the fat crystals, which are separated from the liquid oil phase and are surrounded in an interfacial layer of adsorbed protein will adsorb to the surface of bubbles. During baking, as these fat crystals melt and oil will transfer to the internal surface of the bubble and the remaining crystal-water interface will be used by the bubble as an additional interfacial membrane for expansion without rupture. Consequently, the liquid phase is essential for air incorporation, while fat crystals are responsible from retaining of air at the end of mixing and during initial stage of baking (Brooker, 1993).

In cookie manufacturing, the function of shortening is also to provide required spreading properties yet retain moisture under baking conditions. The interaction between shortening and flour ingredients is also responsible from giving flavor and overall sensation of lubricity of the product. The lubricating effect of shortening greatly influences the final quality of cookies in terms of spreading values. The use of higher amount of shortening gives higher spreading values. Generally, the un-emulsified shortenings are more suitable for cookies (Ghotra et al., 2002).

The influences of different type of fats on cookie and biscuit formulations have been also studied by researchers. It has been shown that the level and type of fat changed dough quality and hence final quality of products. Manohar and Rao (1999) found that the biscuits had significantly higher thickness values when hydrogenated fat or oil was used. Conversely, biscuits made with bakery shortening had better surface characteristics and higher crispness. Jacob and Leelavathi (2007) conducted a study to determine the effects of fat types on cookie formulations. The results of their study showed that cookies containing liquid oil had a relatively harder texture compared to those prepared with bakery shortening and hydrogenated fat.

The role of shortening in cakes

The role of shortening in the cake baking process has been described as forming of stable emulsions which are desired to endure the heat of baking and hence to facilitate aeration by the incorporation of small air cells into the plastic shortening phase during batter-mixing. Thus, entrapment of air bubbles in the continuous phase of the emulsion at room temperature is achieved rather than remaining in the aqueous phase. The mixing process also allows fat crystals to be covered with an interfacial layer of adsorbed protein. Shortening also aids the aeration process during baking. During the baking, these fat crystals melt and the oil expose over the internal surface of the cells, providing an extra interface for expansion and the air bubbles expand serving as nuclei for leavening gases. Therefore, the baking mechanism offers the moving of air bubbles from the fatty phase to the aqueous phase structure. Finally, a fine and smooth texture and a high volume are obtained from the resulted bakery products (Rios et al., 2014).

As aforementioned, the plasticity of shortening also provides incorporation of air bubbles during mixing. Generally, super glycerinated shortenings containing monoglycerides and diglycerides (having surface activity) are used in cake formulations. Due to their ability to form complexes with the amylose fraction of starch, saturated monoglycerides are preferred for cake production and, therefore, softer texture, higher volume, and longer shelf life are obtained. To obtain high voluminous cakes, batter should have many small air bubbles and thus cake shortening plays also a main role in the distribution of air bubbles in batter. In cake shortening, the fat system undergoes crystalline phase change from β' to β crystals under process temperature changes since large of solid fat, associated with β crystals, are much less effective in entrapment of dispersed air. Thus, plastic shortenings, in the unstable β' phase, are more preferred to be used as compared to those plastic shortenings having stable β phase.

In addition to cake shortening, all purpose emulsified shortenings can also be used in cake formulations where adequate creaming performance is required. These shortenings are manufactured by partial hydrogenation of a base oil to an intermediate iodine value. Monoglycerides, lactylated monoglycerides, propylene glycol esters, lecithin, polyglycerol esters, polysorbate 60, and sodium stearoyl lactylate are generally used emulsifiers for this type of shortening (Ghotra et al., 2002).

Oleogels

It is well known that the effect of fat on human health and nutrition can be associated to the quantity of fat consumed, fatty acid composition, as well as the presence of the bioactive micronutrients. The major purpose of the application of oleogels in food industry is the modification of structuring of the oils to provide a plastic having solid-like properties while also possesses a healthier fatty acid profiles to products. Due to the changes in attention of consumers about the drawbacks of solid fats on human health as well as recommendations mentioned in dietary guidelines by different government agencies (EFSA, 2010), the applications of oleogel in food industry received a great deal of attention from researchers working in the field of health. Furthermore, there is still a need for the growth of this field to produce healthier products.

The available studies over the past decades have shown that the replacement of dietary saturated fats with unsaturated fats decreased risks of cardiovascular disease (Bier, 2016; Malhotra et al., 2017; Forouhi et al., 2018). The deleterious effects of saturated and trans-fat consumption on health have been associated to their role in elevation of LDL (low density lipoprotein, bad cholesterol). In particular, it has also been reported that trans-fatty acids have been shown to be linked with elevated levels of LDL and reduced levels of HDL. Conversely, saturated fatty acids of shorter length have been revealed to increase LDL levels without changing HDL level (Co and Marangoni, 2012). Although, fatty acid profile is the main concern, it has been reported that bioactive phytochemicals present in fats and oils such as tocopherols (soy-bean and corn oils), tocotrienols (palm and rice bran oils), oryzanol (rice bran oil), sesamin and sesamolin (sesame oil), and polyphenols (olive oil) have the ability to interact with reactive oxygen species protecting fatty acids from lipid peroxidation is another important effect on health. WHO (World Health Organization) has also highlighted the importance of a shift in fat consumption away from saturated fats and trans-fats to polyunsaturated fats. According to WHO, up to 30% of total energy intake should be supplied from total fat and less than 10% of total energy intake needs to be taken from saturated fats. In addition, it has been recommended that the intake of trans-fats should be limited to less than 1% of total energy intake (https://www.who.int/news-room/fact-sheets/detail/healthy-diet). Similarly, in past decades, researchers also stated that the risk of cardiovascular disease due to the consumption of saturated fat may be not only be related to LDL cholesterol but also blood triglycerides (TGs). It has been reported that LDL cholesterol increases during the digestion, transportation, and metabolism of dietary fats (especially saturated fats). However, saturated fats increase blood TG concentrations that subsequently prevent LDL-cholesterol receptor activities in the liver and thus obstruct the clearance of LDL cholesterol from circulation. These findings summarized the critical role of managing of TG on the reduced the risk of cardiovascular disease (Zetzl and Marangoni, 2011).

Conversely, in the medical literature there are still full of articles arguing opposing positions. Recent studies have questioned the simple explanation of the relationship of dietary saturated fats and of individual saturated fatty acids to cardiovascular disease. For example, it has been found that when saturated fat is replaced by carbohydrates, this not only reduces LDL cholesterol but also lowers HDL cholesterol and increases triglycerides (Bier, 2016; Malhotra et al., 2017; Forouhi et al., 2018). These findings which were considered less important for researchers in the past showed that total fat and types of fat cannot be directly associated with cardiovascular disease. Although, controversies continue to exist, current recommendations have also highlighted that the importance of a critical look at the evaluation of scientific understanding about dietary fats and health. Therefore, novel approaches for processing fats and oils for human consumption are necessary to produce nutritionally well balanced food products to fulfill the expectations of present-day health-conscious consumers (Zetzl and Marangoni, 2011).

Oleogels can be defined as the structured solid-like materials in which a high amount of liquid oil entrapped within a self-standing, anhydrous, thermoreversible, three dimensional network of gelator molecules (Mert and Demirkesen, 2016a). The interactions having the role in gelation process are summarized as hydrogen bonding, π-π stacking, electrostatic and van der Waals interactions (Singh et al., 2017). They allowed to 1-dimension growth and these 1-dimension structures form junction zones relating numerous 1D structures and finally that creates 3-dimensional networks. Thus, the potential use of this technique received a great popularity from both food industry and scientific fields and now oleogels are being used for various food products such as chocolates, chocolate pastes, confectionery fillings, ice creams, cream cheese, frankfurters, emulsions, cookies, and cakes (Table 1).

It is known that possible oil migration during storage creates significant quality defects during the preparation chocolate. It has been hypothesized that liquid TAG within the chocolate matrix can migrate to the surface of chocolate and then recrystallize resulting in oil migration which is considered the main cause of fat bloom development. Fat bloom is especially observed in filled chocolate products. Furthermore, as one of the main quality problems in the chocolate industry these bloomed chocolate products are characterized by some quality defects such as the loss of its initial gloss and the formation of a grey-whitish haze, which makes the product unappealing from a consumer point of view (Delbaere et al., 2016). It has been demonstrated that oleogels provided higher melting points to chocolate or chocolate-derived products (Blake et al., 2014).

It has been reported that oleogels can satisfactorily be used to overcome fat bloom problems in chocolate and filled chocolate products. Similarly, this technique has also been used for the production of creams, which later used in cream filled cookies to inhibit fat bloom and texture defects. It has been revealed that oleogels gave thixotropic behaviors to confectionery filling fats and this property provide a possible capability to prevent migration of filling fat to coating fat (Si et al., 2016). The studies showed that oleogels might also be a good alternative to produce heat resistant chocolate (Stortz and Marangoni, 2013; Stortz et al., 2015). Oleogels can also be applied in dairy products with the purpose of producing a low fat ice-cream (Moriano and Alamprese, 2017). Oleogels has been also utilized for structuring of spreads that gives spreading, the structural consistency, and the desired consumer mouthfeel characteristics (Yılmaz and Öğütcü, 2015a, 2015b). They have also been utilized for the production of comminuted meat products and ground meat products with the attempt of offering emulsion stability as well as enhancement of the fatty acid profile. For this purpose, sausages, frankfurters, and other processed meats have been the point of interests (Zetzl et al., 2012). By the application of this novel structuring materials, the fatty acid profile of the gelled oils and the functionality and texture of lipid phase in meat products are improved (Jimenez-Colmenero et al., 2015). Oleogels can also minimize oil oxidation and color changes of products since oleogels can impart heat resistance and provide moisture barriers (Gravelle et al., 2012). The controlled release of bioactive compounds and functional ingredients such as carotenoids, flavoring compounds, and essential unsaturated fatty acids can also be achieved by the application of oleogels. Encapsulation of significant components within such termostable gel complexes provides a resistance to oxidation. Furthermore, the entrapment of these compounds in a gel matrix provides the controlled release of these compounds upon dissolution or deformation of the gel (Hughes et al., 2009; Co and Marangoni, 2012). Recent years, the applications of oleogels in bakery products have gained great interest. Oleogels have recently been utilized for the production of bakery products such as cookies and cakes and it has been observed that the utilization of oleogels in these products provided significant improvement over the use of liquid oil (Mert and Demirkesen, 2016a, 2016b; Oh and Lee, 2018). In our one of the latest study, we also explored the application of oleogels in gluten-free bakery products and we demonstrated that healthier gluten free products can be produced with the incorporation of oleogels (Demirkesen and Mert, 2019).

Oil structuring methods

The most common oil structuring methods can be categorized in four different systems; (i) direct dispersion, (ii) indirect method, (iii) structured biphasic systems, and (iii) oil sorption. Among them, the most frequently applied one is the direct dispersion of a gelator into liquid oil in which lipid-based gelators (lipid-based (waxes, fatty acids and monoglycerides, ethylcellulose, and colloidal silicon dioxide) are directly dispersed into oil phase at temperatures above their melting points followed by cooling to lower temperatures either under shear or gentle conditions. The cooling of sol creates nucleation and crystal growth, resulting in the formation of aggregation and hence self-assembled networks. Although, this structuring method is described as an extension form of conventional structuring process involving solid fats, this method presents differences in terms of the type and the morphology of crystals formed, the tendency of their unidirectional growth and lower aggregation among the formed crystals which provide formation of network at much lower mass fraction of crystalline phase (Patel and Dewettinck, 2016). During the application of this method, the advantages of mixed system gels over monocomponent gels such as those prepared using fatty acids and wax esters due to the gelation efficiency has been stated by the authors (Ojijo et al., 2004; Pernetti et al., 2007; Han et al., 2014; Singh et al., 2017).

Indirect method is the use of a polymer for gelling vegetable oil to form structural framework in an aqueous solvent or water continuous emulsion, which requires the careful removal of aqueous solvent for the conservation of the gel network. The formation of such unique microstructure provides entrapment of a large amount of liquid oil by the soft solid without any oil leakage over extended period of storage (Patel and Dewettinck, 2016).

The oil sorption is a method in which the enrichment, in this case by oil, of a porous material or an increase in the density of a fluid in the vicinity of an interface is achieved. Porous additives having high specific surface area and other absorbent fillers have been employed to retain moisture and provide the consistency, flowing characteristics and texture to end products. For this purpose, fibrous cellulose material which provides oil absorbing characteristics due to capillaries has been used. In bakery products, porous starch particles have also been applied to form such a structured system (Patel and Dewettinck, 2016; Lee, 2018).

The water-oil biphasic systems, giving a “gel-like” behavior, can be classified as (i) water continuous emulsions structured using biopolymers (proteins and/or polysaccharides) acting as emulsifiers and thickening or gelling agents such as cheese, yogurt, and dairy-based desserts etc.; (ii) highly concentrated water continuous emulsions in which the structuring is created from closely packed dispersed droplets at high packing fractions such as mayonnaise, sauce; and (iii) oil continuous emulsions that formed using crystalline network of fat particles such as margarine, butter, and spreads (Patel and Dewettinck, 2016).

Oil type, oleogelator type, and concentrations are important factors that influences rheological, thermal, and textural properties of oleogels and hence of the quality of resulted products in which oleogels are incorporated (Pehlivanoglu et al., 2018a). In literature, different oil types such as sunflower oil, olive oil, hazelnut oil, canola oil, rice bran oil, corn oil, soybean oil, grape seed oil, rapeseed oil, and flaxseed oil have been used to obtain oleogels (Zetzl et al., 2012; Zulim Botega et al., 2013b; Patel et al., 2014c; Yılmaz and Öğütcü, 2015a; Lim et al, 2017; Park et al., 2018). As expected, oils having higher proportion of saturated fatty acid resulted in lower gelling concentrations. Thus, higher viscosity values were observed in oils having higher saturated TAG and melting fatty acids. The relationship between oleogelators and oils are also found to be effective on gelling ability of oleogelator. As aforementioned, lower contents of oleogelator are needed when oils having higher oleic acid contents are used (Pehlivanoglu et al., 2018a). In literature, many different types of oleogelator such as triacylglycerols, diacylglycerols, monoacylglycerols, fatty acids, fatty alcohols, waxes, wax esters, sorbitan mono-stearate, phospholipids, phytosterols and the mixtures of fatty acids and fatty alcohols, lecithin and sorbitan tri-stearate and phytosterols and oryzanol have been used for the formation of oleogels. However, in case of food applications, good oleogelator functionality, suitability for different products, relatively low price, commercial abundance and effectiveness in lower concentration are the factors influencing of the selection of oleogelator. Among them, waxes have shown to have capability to create a well-formed network with strong oil-binding properties, self-assembled fibrillar networks, and polymer gelation. Therefore, they have been indicated to be the most efficient oleogelator according to their gelation strategies (Toro-Vazquez et al., 2007, 2013; Dassanayake et al., 2009; Rogers et al., 2014; Blake and Marangoni, 2015; Doan et al., 2015; Hwang et al., 2015). Furthermore, the low polarity, long chain length, and high melting point of the components found in waxes provide excellent crystallization properties to liquid oil. Furthermore, they have ability to form such 3-D network even at concentrations lower than 10% (Mert and Demirkesen, 2016a).

To obtain desired qualities from food products, the interaction between oil type and wax type and wax concentrations are considerable. For this purpose, several studies have been conducted on rheological, crystallization and thermal behavior of waxes and these studies have already been reported the relationships between waxes and oil types and the oil-structuring properties of waxes (Toro-Vazquez et al., 2007; Dassanayake et al., 2009; Doan et al. 2015; Patel, 2015a, 2015b; Mert and Demirkesen, 2016a, 2016b). The gelling ability of gelators changes based on fatty acid composition, molecular weight, and acyl chain length of the oils. Furthermore, the concentration of oleogelators used in the oleogel production also varies depending on their type. Generally, lower amount of gelators were found to be needed for preparing of oleogels with vegetable oil containing high oleic content such as olive oil, rice bran oil, and high oleic sun flower oil (Pehlivanoğlu et al., 2018a). The utilization of different waxes for oleogel formulation noticeably affected all the characteristics. Studies showed that thermal characteristics of the edible oil were influenced by the degree of the oil saturation and it has been observed that vegetable oils having higher saturated fatty acid content formed stronger oleogel structure. Higher viscosity values and harder oleogels were obtained from oil containing higher saturated TGA and high melting fatty acid. Rheological measurements indicated that beeswax and candelilla waxes formed strong gels with rice bran oil and the high strong thixotropic behavior reflected their potential use for the food industry (Dassanayake et al., 2009). Crystallization behavior of waxes showed that fine dispersion of long needle like crystals in liquid oil phases of rice bran wax provided good organogel-forming properties over carnauba and candelilla waxes (Doan et al., 2015).

In addition to waxes, ethylcellulose is the most widely preferred polymer as an oleogelator. The gel formation ability of this semi-crystalline polymer was related to its role in formation of a more efficient polymer–polymer hydrogen-bonding. Shellac has also been used to convert liquid oil into oleogel. It has been identified as a structuring agent that capable of gelling edible oil even at low concentrations. The use of shellac was tested for spreads, chocolate paste formulations, and cake preparation (Patel et al., 2013; Patel et al., 2014c; Patel and Dewettinck, 2015).

Studies conducted on the application of oleogels in bakery industry showed that waxes can be good alternative for oil structuring method. It has been reported that most of waxes are characterized by their high melting points. Natural waxes as the mixture of hydrocarbons and fatty esters (an ester of a fatty alcohol and a fatty acid) gives harder, less greasy, and more brittle textures.

Candelilla wax, a plant-based wax, is derived from the leaves of candelilla shrub (*Euphorbia cerifera* and *Euphorbia antisyphilitica*). It is approved by the Food and Drug Administration (FDA) and can be used as a glazing agent and binder for chewing gums. It is considered as chemically heterogonous. Since it has hentriacontane as major n-alkalene component and other *n*-alkanes as minor components (i.e., nonacosane and tritriacontane), it provides the possibility of creating of edible organogels using vegetable oils as the liquid apolar phase (Toro-Vazquez et al., 2011). It has hard, brittle and quite smooth texture. It melts quickly, has a nice glide and is absorbed readily. Thus, products containing candelilla wax spread easily and thinly. As compared to beeswax, it has a higher melting point (60–73 °C) and, therefore, it produces harder products.

Carnauba wax is obtained from the leaves of the Brazilian palm tree, *Copernicia cerifera C. Martius*. It has very high melting point compared to other natural waxes and is one of the hardest waxes. Similar to Candelilla wax, it is considered chemically heterogonous and quite brittle (Blake et al., 2018). The melting point of it is 80–85 °C. It shows excellent oil-binding capacity for ester oils and mineral oils. It can be used as a hardener for other waxes and it can be applied to raise the melting points of wax mixtures.

Beeswax is a bee product secreted by special wax glands in the abdomen of younger worker bees to build the honeycombs where to store honey. It has gained considerable interest due to its natural origin, regulatory approval for use in food and easy availability. Furthermore, researchers have highlighted the antimicrobial activity of beeswax. It has excellent gelation properties and is effective as structuring agent even at very low concentrations. It assists emulsifying properties and improves consistency of products. Its melting point is approximately 65 °C. It can be used for stabilizing of oils in both anhydrous and emulsion systems. It is also good plasticizer, coating and gelling agent.

Rice bran wax is obtained through the cold press dewaxing of rice oil expelled from rice bran wax found in rice kernel. It is natural wax and it has the highest melting point (78–82 °C) after carnauba wax. It has been reported that the characteristic physical properties of purified rice bran wax are comparable with those of carnauba wax. Because of the low concentrations of minor components, rice bran and sunflower waxes are considered chemically homogenous as opposed to candelilla, carnauba, and beeswax waxes. It has been reported that rice bran wax is the most crystalline wax and hence it can form stronger gel networks. It has also been reported that rice bran wax is a superior binder of oils.

Sunflower wax as natural components of sunflower oil recovered in the winterization process during oil refining. It is a hard, crystalline, high melting point vegetable wax (74–77 °C) (Blake et al., 2018).

The crystallization behaviors of waxes have also been documented. Dassanayake et al. (2009) reported that because of high melting and crystalline temperatures of rice bran wax, it is the most crystalline wax and that possesses the stronger gel network. Conversely, the authors hypothesized that the presence of minor molecular components in candelilla and carnauba waxes formed mixed molecular packing arrangements during crystallization and hindered the formation of highly organized crystal structures. The studies conducted on the morphological characteristics of waxes indicated that rice bran wax forms needlelike crystals having 20–50 μm long. Similar to rice bran wax, beeswax and sunflower wax has been reported to have needlelike crystals but sunflower wax has the longest and beeswax has the shortest crystal length. Conversely, candelilla and carnauba crystals (less than 10 μm in diameter) have spherulitic structures. The higher ester contents and lower concentrations of minor components provide chemically homogeneous structure to rice bran wax, sunflower wax, and beeswax and have a role on their crystalline structure. They have highly ordered packing arrangements that possess the growth of larger and needlelike crystals. It has also been reported that homogenous waxes having higher ester contents and lower minor components show lower critical gelling concentrations (C^*) compared with heterogeneous waxes. Such lower critical gelling concentrations showed the minimal required amount of gelator to form an oleogel. These lower critical gelling concentrations also provide higher oil binding capacities. It has also been hypothesized needlelike crystal structures of sunflower and rice bran waxes has also role on oil binding capacities and the entangled network structures of these waxes provide capable of entrapment of liquid oil efficiently.

Shellac is wax excreted by an insect living "a female lac bug," on trees in the forests of India and Thailand. It is the hardest naturel wax after carnauba wax. It also has high melting point (77–86 °C) and approved as GRAS (generally recognized as safe). Patel and coworkers has identified the use of shellac (a food-grade resin) as a new structuring agent. The authors tested the potential of oleogels formed by shellac for preparation of emulsifier-free, structured w/o emulsions (spreads), a replacer for oil-binders in chocolate paste formulations and a shortening alternative for cake preparation (Patel et al., 2013, 2014c; Patel and Dewettinck, 2015). The authors have showed that shellac oleogels can be used for some interesting food applications. In addition, a number of studies also reported the utilization of hydrocolloids as alternative oil-structuring ingredients. Various kinds of oleogels such as methyl cellulose, hydroxypropyl methylcellulose, xanthan, and chitin have been used as structuring agent (Patel et al., 2014a, 2014b; Patel and Dewettinck, 2015; Tanti et al., 2016; Oh and Lee, 2018).

Oleogel applications in food industry

Oleogels in bread formulations

In the study of Ye et al. (2019), oleogels structured by ethylcellulose polymers. The performance of ethylcellulose oleogels against commercial shortenings in bread formulations was tested. Ethylcellulose oleogels were prepared using the base oil (degree of saturation 20%, 25%, and 30%), ethylcellulose polymers (1%, 2%, 3%, 4%, and 6%, w/w), and emulsifiers (1%, w/w) and then each oleogels was assessed for suitability as bakery shortenings. The authors selected ethylcellulose100 among different ethylcellulose polymers (ethylcellulose20, ethylcellulose50, ethylcellulose100, and ethylcellulose200) because it gave the highest hardness with minimal oil migration. Furthermore, the oil solution containing ethylcellulose100 presented continuous gel network without any suspending particulates.

Rheological measurements showed that pseudoplastic behavior of olegels was directly related to the structure of the gel network. It has been stated that the higher the molecular weight (represented by viscosity values) means the more opportunities for the OH groups in ethylcellulose polymer backbone to interact with other molecules and form more H bonds. Conversely, it has been observed that ethylcellulose200 which has the highest molecular weight among all ethylcellulose polymers had interestingly the lowest viscosity values. Although, having the longest polymer chain length it was expected that ethylcellulose200 should have created the strongest gel network, but the polymeric structure of it hindered its ability to form a smooth solution with soybean oil. Therefore, the structure of ethylcellulose200 hindered the entry of oil molecules into ethylcellulose200 under heating and swelling conditions during oleogel preparation. The findings of this study showed that the characteristics of ethylcellulose oleogels are dependent upon the molecular weight and, thus, the mechanism for ethylcellulose oleogel formation is completely different from the crystalline formation mechanism by those low-molecular weight oleogelators such as waxes. Therefore, to form a stable gel network, the ethylcellulose molecules first form entangled structure. Then, with the dissolution of oil into ethylcellulose, the solubilized oil should be trapped among the polymeric network formed by ethylcellulose H bonds during the heating process. As discussed earlier, bread shortening should have a wide plastic range at room temperature and its main function is lubrication during dough mixing process. Thus, it helps the incorporation of air for the strengthening of the dough and the adequate gas retention during initial stages of baking. Among all ethylcellulose polymers, ethylcellulose100 oleogel was identified as the most suitable ethylcellulose polymer to be used in shortening formulation since it had good gel stability, excellent hygroscopicity, and good air-incorporation ability.

As aforementioned, the existence of β' polymorph, which provides a smooth texture can be stable for a long time and thus it is often desired during storage of high amount of fat containing products. Conversely, the existence of high-melting β form often gives a grainy texture that is less favorable in margarines, spreads, and shortenings. X-ray Powder Diffraction spectra of the samples showed that β' polymorph is dominant in commercial shortening, while shortenings containing ethylcellulose oleogels showed higher β form, which could be related to the use of palm stearin as the main ingredient in the base oil.

Among different emulsifiers (glyceryl monostearate, triglyceryl monostearate, glyceryl distearate, and Sorbitan stearate (S-60), triglyceryl monostearate was found to be the most effective emulsifier to work with ethylcellulose 100 shortening in baking applications. Triglyceryl monostearate strengthen air incorporation ability of the shortening while creating evenly distributed fine crystals in dough system.

Quality measurements of breads indicated that the specific volume of the bread made with ethylcellulose100 oleogel shortenings and triglyceryl monostearate was found superior to breads made with commercial shortening (Figure 1). Furthermore, breads formulated with oleogel and triglyceryl monostearate had softer texture compared with breads made with commercial shortening. This result might be attributed to air-incorporation ability of oleogel shortenings. Furthermore, the ability to be miscible with oil makes

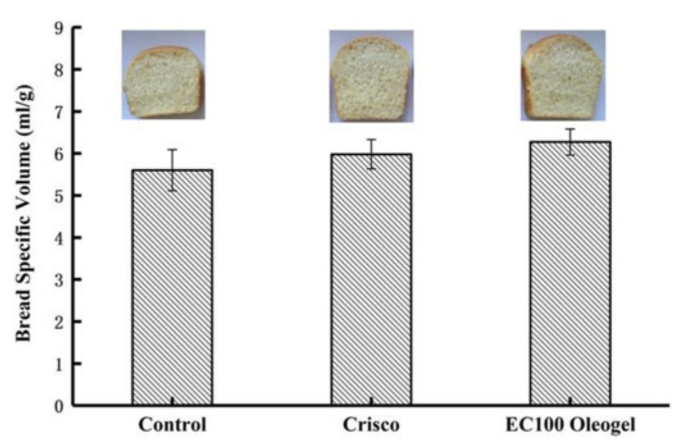

Figure 1. The specific volume of breads made with ethylcellulose (EC100, 4%) oleogel-based shortening using triglyceryl monostearate (TMS) as an emulsifier in comparison with the control and that made with Crisco shortening. Reproduced from Ye et al. (2019) with the permission from the publisher.

ethylcellulose100 the most suitable oleogelator for shortenings because it usually contains 95% or more oil in it. Comparing their findings with previous studies, the authors suggested that shellac can be more suitable for the preparation of water-in-oil emulsions containing 20% water. Conversely, carnauba wax and candelilla wax can interact with protein in dough system, giving good extensibility and spreadability but inferior shortening effect (Patel et al., 2013; Mert and Demirkesen, 2016a, 2016b).

Oleogels in cookie formulations

During the preparation of cookies samples, shortening should provide lubricity and tenderness rather than aeration hence it does not influence the water absorbing properties of flour. It is well known that shortening plays a critical role in the formation of three-dimensional gluten network structure in bakery products. In certain bakery products such as breads, extensive gluten network formation is required, however, in case of the ones made with short dough such as cookie; strong gluten network is not desired (Mert and Demirkesen, 2016a, 2016b). Therefore, short dough products are made with restricted amount of water and high amount of shortening. Consequently, shortening is an essential ingredient in cookie dough since fat crystals form a barrier film around the gluten strands and avoid extensive crosslinking in the gluten network during mixing.

Previous studies indicated that the potential of candelilla wax for the formation of oleogels with safflower as well as soybean oil (Toro-Vazquez et al., 2007). Jang et al. (2015) has conducted a study to evaluate the potential role of the oleogels of candelilla wax with canola oil for alternative to shortening in cookies. For this purpose, the authors prepared the oleogels of canola oil with candelilla wax and then, characterized their rheological properties. The oleogels were incorporated into the formulation of cookies as a shortening replacer and their influences on the physico-chemical properties of the cookies were also investigated. The firmness of the oleogels was found to be lower compared to the firmness of shortening at room temperature. However, oleogels prepared with increasing levels of candelilla wax showed a tendency to become firmer. The results of rheological measurements showed that incorporation of candelilla wax (3% and 6% by weight) to canola oil provided solid-like properties to oleogels. The viscosity of the oleogels containing higher amount of candelilla wax was found to be highly dependent on the temperature change. It has been stated that the viscosity differences among the oleogel samples might affect the baking performance of cookies. The dynamic viscoelastic properties of the cookie dough samples showed that cookie dough prepared with shortening had higher values of viscous (G') and elastic (G') moduli values compared to the oleogel-incorporated samples. This finding might be attributed to the firmer texture of shortening. According to the fatty acid compositions of the cookies, as expected the predominant component of the shortening-incorporated cookies was palmitic acid (16:0, 41.9%), while it was oleic acid (18:1, 62%) in case of oleogel containing cookie samples. The use of oleogels increased with the level of unsaturated fatty acids up to around 92%.

The result of quality measurement of cookie samples indicated that desirable spreadable characteristics with the increased diameter and decreased height were obtained from cookie samples prepared with oleogels. The authors hypothesized that this result could be related to the low viscosity of the oleogels at the baking temperature which could play a positive role in the expansion and collapse of the cookies during baking. The effects of oleogels on the snapping property of cookies were also investigated by using a three point bending test. It has been observed that greater force was found to be needed to break the control cookies with shortening as compared to that of the oleogel-incorporated cookies. This finding might be attributed to softer eating characteristics of the cookies prepared with the oleogels.

The effects of hazelnut oil-beeswax and hazelnut oil-sunflower wax oleogels on cookie samples have also been studied (Yılmaz and Öğütcü, 2015b). The weight and thickness of the cookies prepared with commercial bakery shortening were found to higher than those of the cookies made with the oleogels, whereas the diameters values of cookies were not different. The higher weight and height of the cookie samples made with shortening might be related to their higher moisture contents. The higher moisture content and hence higher water activity of cookies made with shortening might be attributed to the amount of water present in the shortening and/or to its higher water retention capacity. As aforementioned, shortening should offer lubricity rather than aeration in the production of cookies. The lower the aeration in cookie dough results in the higher spread ratios. Thus, the cookies prepared with oleogel samples had higher spreading values. As compared to cookies made with oleogels, cookies prepared with shortening had significantly higher harder but lower fracturability values. Although, contradictory findings available about the effect of oleogels on hardness and fracturability values, the authors related their findings to the fact that oleogels composed of very fine β' type crystals are good enough to form less hard but more fracturable cookie texture. Cookies made with oleogel had lower water activity hence longer biological shelf life. Overall results of the study showed that in case of almost all quality parameters (physico-chemical, textural, flavor and texture profile analysis, consumer hedonic tests and storage stabilities), the oleogel cookies found to be similar with shortening containing ones. According to sensory analysis, oleogel cookies were found to be better than cookies prepared with shortening by consumers. Thus, the authors suggested that wax oleogels can be used as cookie shortening successfully.

In one of the study (Mert and Demirkesen, 2016a), the potential application of two different oleogels employed to produce cookies. Incorporation 2.5 g/100 g and 5 g/100 g wax (candelilla wax and carnauba wax) into sunflower oil led to self-standing oleogels of which rheological characterization revealed their highly shear dependent behavior.

From fatty acid analysis, it has been observed that the oleogels had clearly higher levels of unsaturated fatty acids compared to the shortening reflecting their potential to be a healthier alternative for bakery shortenings. The incorporation of waxes into sunflower oil resulted in certain increases in the amount of saturated fatty acids since waxes also contains many other substances such as very long chain hydrocarbons, acyl-glycerols, sterol esters, etc., in addition to long chain fatty acids. It is well known that solid fat content of edible oils and fats is the feature that defines the percentage of the solid parts of fats at certain temperature. Therefore, it indicates the variations in consistency and plasticity of food products at different temperatures. Since solid fat is critical to obtain a well-aerated, tender, lubricated, and viscoelastic dough structure, in case of bakery products fats having relatively high SFC values are used during the mixing process. In case of cookies, shortenings must have a certain solid fat index especially at dough mixing temperature. It has been identified that shortenings having high solid fat index do not have enough oil volume for suitable aeration, while shortenings having low solid fat index do not capable of holding air until mixing is complete (Rios et al., 2014).

Although, rheological measurements indicated that oleogels, especially the ones prepared with 5 g/100 g wax, had comparable rheological characteristics with shortening, it has been reported that commercial cookie shortening had significantly higher SFC values at temperatures usually employed during dough mixing (20–30 °C). The authors proposed that this might be related to the gelation of waxes in which mechanism liquid oil is trapped in the crystal particle network formed by waxes. It should be noted that, although, oleogels had significantly lower SFC values, they were able to form self-standing structures. SFC values of both oleogel types increased with the elevated levels of waxes (Figure 2). Furthermore, it has been observed that candelilla oleogels had slightly higher SFC than carnauba oleogels. Complex modulus values of samples were determined as a function of temperature during constant rate crystallization. The results revealed that all the samples were in a fully melted state and at the beginning of the crystallization, elastic modulus values of the samples were very low indicating their liquid like structures. Upon cooling, at the onset temperature relatively small number of crystals formed leading to slight increases in the complex modulus values of the samples. However, when the onset temperatures were passed, all samples started to form crystals displaying more solid like structures with higher moduli values. Generally, higher complex moduli values were obtained with candelilla wax oleogels. However, it should be noted that during determination of complex moduli values, the crystallization processes occurred within the rheometer plate and the measurements were conducted at very low strain amplitude (0.001). Thus, the particulate gels formed with wax gelators were unperturbed. We mentioned that oleogel network structure formed by the crystal particles could be very susceptible to shear which might be resulted in formation of smaller aggregates. Subsequently, since the rheological properties of oleogels depend on high shear and time dependent natures, we hypothesized that the obtained result of higher complex modulus values from 5 g/100 g candelilla wax or

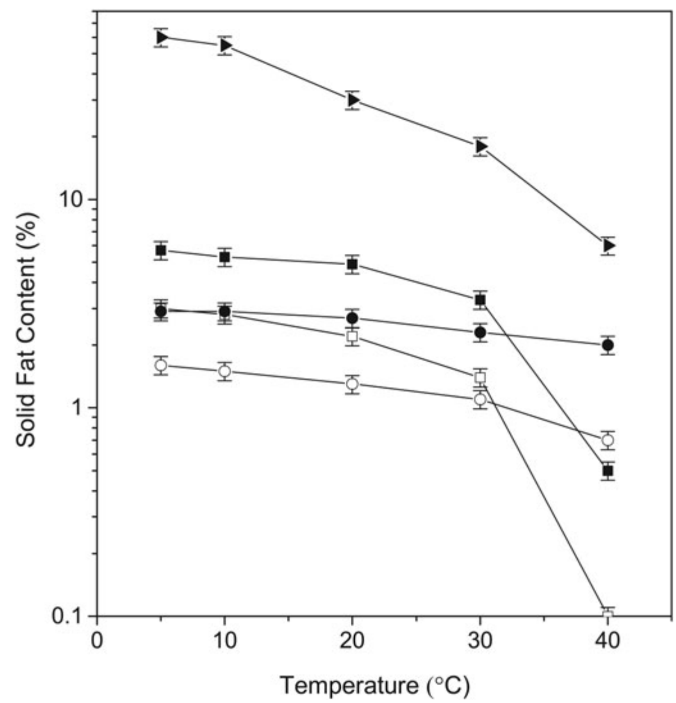

Figure 2. SFC values of shortening (solid triangle), 5 g/100 g candelilla wax oleogel (solid square), 5 g/100 g carnauba wax oleogel (solid circle), 2.5 g/100 g candelilla wax oleogel (open square), 2.5 g/100 g carnauba wax oleogel (open circle). Reproduced from Mert and Demirkesen (2016a) with the permission from the publisher.

5 g/100 g carnauba wax oleogels compared to commercial shortening might be related to their unperturbed structure.

In literature, it has been documented that oleogels display significantly high elastic properties and high viscosities in the linear regime due to their space-filling characteristics. The rheological properties of oleogels can markedly be changed as a result of structural breakdown under deformation conditions and hence under dough mixing conditions, oleogels may quickly lose their solid like structure as a result of shear forces (Mert and Demirkesen, 2016a). Consequently, they may become much softer than shortening. As can be seen in Figure 3 shearing caused not only significant increases in tan δ values of oleogels but also noticeable decreases in both their elastic and viscous moduli values. In this study, extensibility of dough samples was also evaluated to determine the degree of gluten network formation. Dough samples containing shortening had the lowest extensibility reflecting a characteristic property of short dough. In case of the use of liquid oil, small droplets of oil dispersed throughout the dough during mixing which were found to be not effective to prevent crosslink formation within gluten network and in aerative actions (Jacob and Leelavathi, 2007). As a result, dough samples containing oleogels had higher extensibility values than shortening containing dough, but they had shorter structure compared to sunflower containing samples. As the amount of waxes used in oleogel was increased, the decreases in extensibility values reduced gluten network formation by crystals. Nevertheless, candelilla or carnauba wax oleogels still contained significant amount of liquid oil that was not as effective as solid fat in forming short dough, oleogel containing dough samples

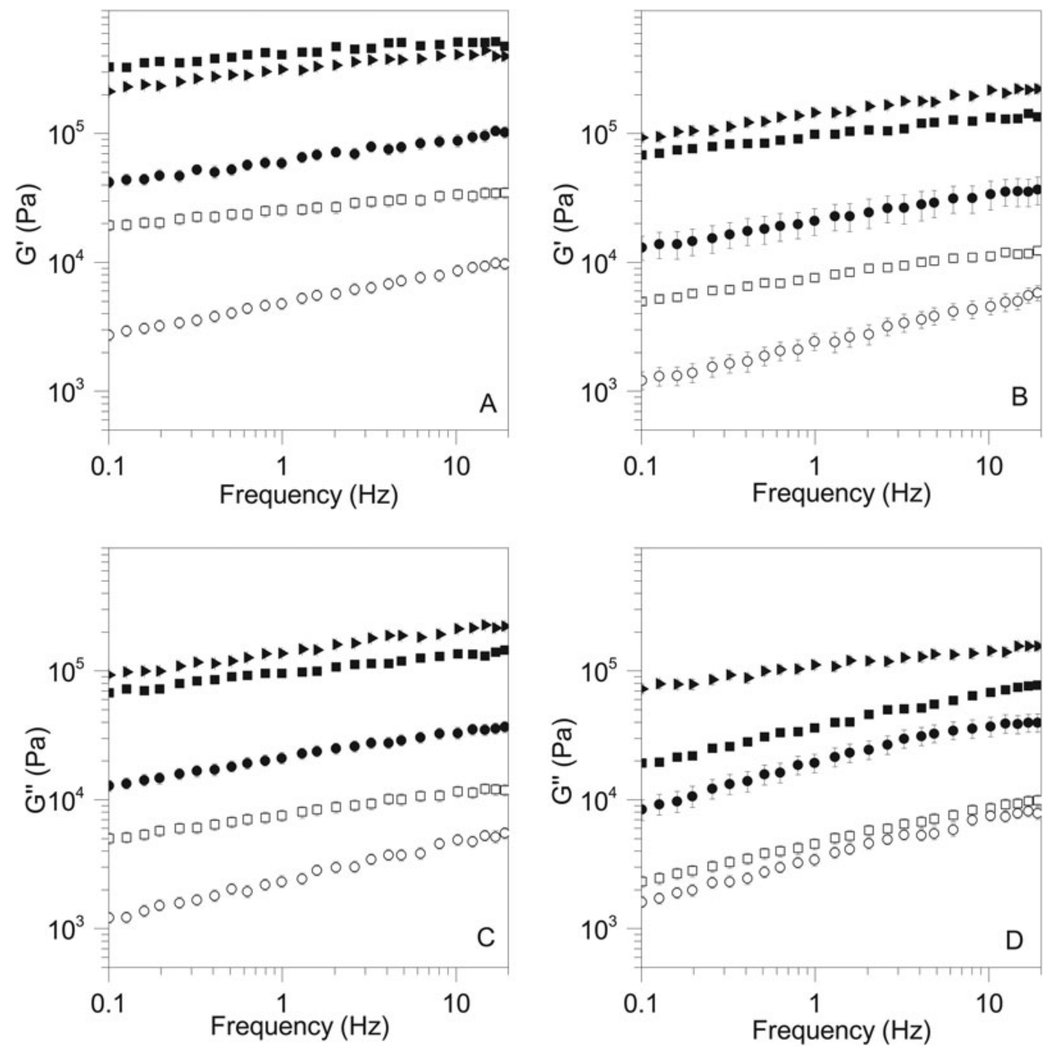

Figure 3. Frequency sweep elastic (*G*) and viscos (*G*) modulus values of perturbed (B and D) and unperturbed (A and C) shortening (solid triangle), 5 g/100 g candelilla wax oleogel (solid square), 5 g/100 g carnauba wax oleogel (solid circle), 2.5 g/100 g candelilla wax oleogel (open square), 2.5 g/100 g carnauba wax oleogel (open circle). Reproduced from Mert and Demirkesen (2016a) with the permission from the publisher.

were found to be still softer than the dough prepared with shortening which indicated the loss of solid like structure of the oleogels when exposed to shear (Figure 3). Quality parameters of cookies were also determined. The breaking strength results indicated that certain increases in SFC with the incorporation of oleogels, which in turn improves air holding ability of dough system resulting in softening of the texture. Overall, the results of study showed that the utilization of oleogels improved the cookie quality compared to sunflower oil containing cookies. However, the finding of our study showed that the functionality of the oleogels was not sufficient to obtain the similar quality with shortening containing ones. The contradictory findings reflected the necessity of further optimization of oleogels to match quality characteristics of commercial shortening containing cookies. While saturated fatty acid content of bakery products can be reduced with the replacement of shortening with oleogels, to maintain desired physical properties of the baked products can be challenging.

We also employed the use of oleogel/shortening blends in bakery products (Mert and Demirkesen, 2016b). For this purpose, the oleogels of canola oil with candelilla wax prepared at two different concentrations (3% and 6% w/w) and the oleogel/shortening blends at different ratios (30:70 and 60:40) were formed. Then, the prepared oleogels and oleogel/shortening blends were partially incorporated into the cookie formulations as a shortening replacer and their influences on the rheological properties of cookie dough formulations and also on the quality parameters of cookies were investigated. The results were compared with shortening and canola oil containing doughs/cookies. The findings of this study has also shown that at unperturbed state both oleogels and oleogel/shortening blends formed self-standing structures with rheological properties comparable to shortening. Oleogel/shortening blends could withstand to shear, while application of shear quickly transformed oleogels. The findings of this study indicated that higher shortening amount in blends enhanced shear sensitivity of the samples and led to dough samples having texture properties closer to short dough properties.

Quality measurements of cookie samples showed that the use of liquid oil in formulations resulted in higher spread ratios and hardness values. However, incorporation of oleogels provided enhancements in physical properties of cookies compared to liquid oil, but further improvements were obtained with the use of oleogels-shortening blends. Partial replacement of shortening with oleogels provided much more acceptable dough and cookie characteristics than total replacement. Consequently, we suggested that gradual replacement of shortening with oleogels may be a suitable approach for reduction of saturated fat in short dough products.

Hwang et al. (2016) conducted a study to examine the feasibility of cookies in which shortening is replaced with oleogels made with different types of different oils (olive oil, soybean oil, and flaxseed oil) and different waxes (sunflower wax, rice bran wax, beeswax, and candelilla wax). The results revealed that both wax and oil types significantly affected properties of oleogel such as firmness and melting behavior. It has been observed that sunflower wax and rice bran wax gave the highest hardness to cookie dough. It has been stated that firmness values of oleogels did not directly reflect the dough hardness which showed that the effects of wax on dough hardness may be altered by other ingredients in dough or by physical changes of oleogel phases during the kneading process. In this study, differential scanning calorimetry (DSC) was also used to understand melting behaviors of oleogels and cookie dough. It has been observed that melting behaviors of dough samples were generally very similar to that of oleogels. This result reflected that that there was no significant change in the oleogel influencing the melting behavior of wax crystals during the kneading. It also indicated that wax crystals stay in the oil phase thus the melting behavior of wax is affected by the surrounding oil. The utilization of oleogels improved handling and shaping properties of dough. Furthermore, oleogels provided better homogeneity to dough samples compared with vegetable oil. Although, wax type and oil type influences properties of oleogels and cookie dough, they did not significantly affect the properties of cookies in terms of spread factor, hardness and fracturability. The authors initially hypothesized that wax crystals might inhibit spreading of dough during baking and that oleogels would provide more crispy cookies. However, DSC results did not correlate with none of characteristics of cookie samples. Overall, the result of this mentioned study demonstrated that some of cookies prepared with oleogels had similar quality parameters with that prepared with shortening. This result suggests that these organogels have high potential as alternatives to shortening.

It has been documented that the physical characteristics of sandwich cookie creams are not well defined and vary among available commercial products. Therefore, in literature, in addition to cookies, the applications of oleogel in cookie creams were also investigated (Tanti et al., 2016). Therefore, the potential of partial and full substitution of icing shortening with freeze dried cellulose derivatives (hydroxypropyl methylcellulose and methylcellulose) structured canola oil in sandwich cookie cream was investigated. In this study, the cellulose derivatives were prepared using a foam templating approach and incorporated as a shortening replacer in food applications. The result of this study indicated that the addition of this shortening replacement resulted in creams having a lower saturated fat content, long term oil stability, less sticky texture. Control samples which containing only shortening resulted in highly sticky and gummy creams, while full replacement resulted in excessively hard creams. It has been found that the partial replacement of hydroxypropyl methylcellulose and methylcellulose structured canola oil with shortening led to formation desirable functional behavior in cookie creams.

Oleogels in cake formulations

As aforementioned, shortening is also an essential ingredient for cake making. Batters are oil in water emulsion (O/W) including dry ingredients, which are either suspended or dissolved in the continuous aqueous phase (Rios et al., 2014). The main purposes of shortening in cake formulations are incorporation of air during mixing and development of air bubbles during baking. The air bubbles formed by fat during the mixing are trapped in the continuous phase of emulsion at room temperature rather than remaining in the aqueous phase. During the baking processes, these air bubbles are transferred to the aqueous phase. Overall, shortening in cake production provides moistness and tenderness, and prolonged shelf life. In addition to the aeration of the batter, shortening in cake is responsible homogenous distribution fat distribution into batter and, thus, providing moistness and tenderness, higher final volume and homogenous crumb structure, and prolonged shelf life. To achieve this, cake shortening must have a creamier structure and a desired plasticity. As aforementioned, cake margarine is a w/o type emulsion and thus small β' crystals of fats in the continuous phase are necessary as they provide firmness and entrapment of air into the batter at a given solid fat content.

Patel et al. (2014c) demonstrated that shellac as a structuring agent is capable of gelling edible oil at low concentrations. To evaluate the potential application of shellac oleogel-based emulsions as a shortening alternative; shellac oleogel emulsion (20 wt% w/o) was prepared. From rheological measurements, it was observed that 10 fold higher elastic moduli values were obtained from shortening containing batter samples. This result might be related to the fact that the absence of solid fat crystals in oleogel-based emulsions led to a lower consistency of shellac oleogel emulsion. The reduces in the firmness of batter affected the air incorporation ability of dough and comparatively higher batter density was obtained from shellac oleogel emulsion batter. In spite of the difference in the consistency and density of the batter, the baked cakes had mostly comparable texture and sensorial attributes. Usually, shortening has a high amount of fat crystals that prevents extensive crosslinking in the gluten network. However, the case of shellac oleogel cakes, the structuring is resulted from the shellac crystal network. Therefore, the higher values of springiness index of the shellac oleogel cakes compared to the cakes containing commercial shortening could be associated to the increased elasticity of the shellac oleogel cakes cake probably due to the higher level of protein crosslinking in the batter. Such higher elasticity of shellac oleogel cakes was also resulted in the higher values of chewiness. According to the results of the sensorial evaluation, cakes formulated with oleogels were found to be comparable in terms of moistness, stickiness, sponginess, volume except uniformity in cell size and crumbliness. The lower uniformity in cell size or voids for the shellac oleogel cake could be related to the uneven distribution of air in the batter which was not efficiently stabilized due to the lack of solid fat crystals in the batter network. This non-uniform distribution of air bubbles led to less coherent and crumbly texture.

Patel et al. (2014a) also tested the functionality of oleogel samples prepared using a combination of water soluble food polymers "xanthan and methylcellulose gum" in cake samples in terms of air incorporation, rheology and texture analysis. The rheological measurements have been exhibited that oleogel samples had lower viscoelastic properties as compared to shortening and margarine. Furthermore, both oleogel and oil batters showed a strong frequency dependence. The consistency of batters can be sequenced from strongest to weakest as follows: margarine > shortening > oleogel > oil and higher consistency of margarine batter compared to shortening batter might be related to the presence of water which probably provided to the wetting and subsequent binding of flour solids. Polarized light microscopy analysis used to determine microstructural properties of cake batters. It has been observed from image analysis that the least air incorporation and the highest batter densities compared to the other batters (margarine, shortening, oleogel containing batters) were obtained from batter containing oil. Instead, the presence of emulsifiers in margarine and shortening samples played a critical role in the stabilization of air bubbles. In case of oleogel samples, fat crystals in oleogel containing samples provided more air incorporation compared to cakes made with oil. The dense appearance, which indicated the structured oil systems forming a network in the matrix as well as the incorporated air bubbles were especially observed in margarine and shortening containing batters. As expected the presence of fat crystals was also observed in margarine and shortening batters.

In the case of hardness and chewiness, cake made with margarine had the best results indicating no significant variations during storage; while all other cake samples showed a significant increase in the hardness as well as the chewiness. The structured oil systems (plastic margarine and shortening) prevent the crosslinking of the gluten network during storage by forming a physical barrier. In case of oleogel containing samples, structured oil had a critical role in minimizing crosslinking of the gluten network and thus they had comparable results with the shortening sample. Yet, a significant enhancement was obtained compared to the oil containing batter. The decrease in the cohesiveness during storage shows weakening of internal bonds thus indicates increases in the brittleness of the cake sample. The margarine and shortening containing cakes had a higher decreases in cohesiveness compared to oleogel and oil cakes. This result might be related to the post crystallization and crystal aggregation occurring in margarine and shortening cakes due to the widely fluctuating temperatures during baking. The oleogel cakes, conversely, had the least drop in the cohesiveness during storage maintaining their soft structure.

Oh et al. (2017) utilized natural waxes (rice bran wax, beeswax, and candelilla wax) to produce sunflower oil oleogels whose physicochemical features in baked cakes as a shortening replacer were compared. The results of rheological measurements revealed that the viscous nature of the cake batters became more dominant when the oleogels (specifically, rice bran and candelilla wax) were used for shortening. These rheological properties of batter samples affected the batter aeration that could be confirmed by X-ray tomographic analysis as well as texture and volume measurements. Shortening containing cake batters had lower specific gravity values as compared to cakes made with oleogel and this result reflected less incorporation of air cells into shortening containing batters.

X-ray micro-computed tomographic analysis proved that the cakes prepared with shortening and beeswax oleogels had finely distributed air cells. Conversely, many large void spaces were observed in cakes made with candelilla and rice bran wax oleogels. The replacement of shortening with oleogels reduced the total porosity of the cakes. The highest specific volume was obtained from cakes made with shortening followed by beeswax, candelilla wax, and rice bran wax, even though no significant difference was observed in the specific volume between the control and beeswax cakes. The texture measurements showed that among all cake samples, cakes prepared with shortening had the softest texture. Among oleogel cakes, the lowest hardness was observed in the beeswax samples but the cakes with candelilla and rice bran wax had harder and chewy in texture. Generally, the shortening cakes had darker color than the oleogel ones exhibiting lower L values. Furthermore, the replacement of shortening with oleogels promoted lower yellowness. Overall, the result of study indicated that beeswax oleogels were the most effective in producing nutritionally superior cakes with comparable quality attributes to the shortening cakes.

In another study, the same authors utilized HPMC to structure sunflower oil into solid-like oleogels and tested their effects on physical properties of muffins (Oh and Lee, 2018). It has been found that the replacement of shortening with HPMC oleogels produced muffin batters with lower viscosity and less shear-thinning behavior. The viscoelastic measurements also showed greater contribution of HPMC oleogels to the viscous nature of muffin batters. The specific gravity of batter had a tendency to increase with increasing replacement levels of shortening, but up to a certain replacement level (50%), the specific volume of baked muffins was not significantly reduced. X-ray micro-computed tomographic analysis showed that air cells were found to be large in size and heterogeneously distributed in the muffins prepared with HPMC-oleogels. However, up to 50% replacement level HPMC oleogels produced muffins without sacrificing their original texture, volume, and total porosity (Figure 4). The decreases in specific volume of the muffins by replacement of shortening with HPMC oleogels could be related with their lower air retaining capacity. Conversely, up to 50% shortening replacement levels, no significant loss

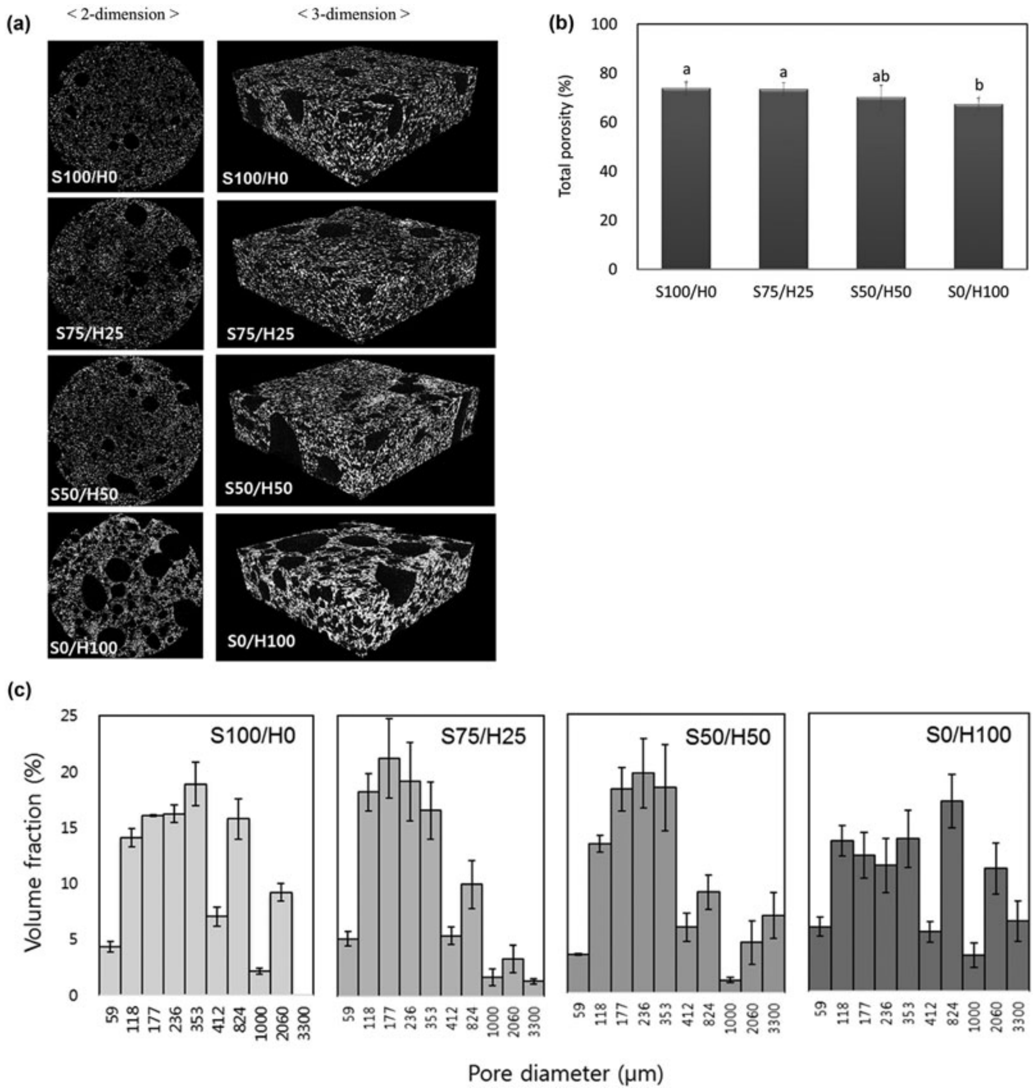

Figure 4. Micro-CT tomographical analysis of muffins; 2D and 3D images (a), total porosity (b), and pore size distribution (c). Reproduced from Oh and Lee (2018) with the permission from the publisher.

in the specific volume was observed. Similar to specific volume values, the replacement of shortening with HPMC oleogels at up to 50% did not negatively affect texture of muffins.

Similar to our studies (Mert and Demirkesen, 2016a, 2016b), Kim et al. (2017) used shortening-oleogel combinations to reduce solid fat content of formulations. Therefore, the authors evaluated canola oil-carnauba wax oleogels as a replacement for shortening in a baked cake system. The authors selected canola oil with carnauba wax oleogels since this combination was considered as more effective in maintaining the quality attributes of cakes due to the presence of solid fat phases. It has been found that the shortening replacement with the oleogels affected the rheological properties and specific gravity of the cake batters. These influences were correlated to the changes in the physicochemical and tomographic properties of the cakes after baking. Because the air cells in the cake batters could not expand enough to coalesce for the formation of larger open cells, more closed air cells were observed in the cakes containing more levels of oleogels (Figure 5). The shortening replacement with oleogels at up to 50% was found to be effective in maintaining the ability to hold air cells into the cake batters. However, further replacement levels led to decreases in volume and increases in firmness of cakes. The replacements of shortening with oleogels demonstrated the reduction in the total porosity and fragmentation index of cakes indicating their more connected solid structure. The authors recommended the use of oleogels for shortening up to 25% which produced cakes with lower levels of saturated fatty acids without quality loss. In another study, the influences of replacement of shortening with oleogels at different levels have been tested for muffin formulations. In this study, grape seed oil was structured with candelilla wax to form oleogels, and then the formed oleogels were used in highly aerated baked goods, muffins. In this case, it has been found that shortening could be successfully replaced with oleogels up to 25% by weight with comparable quality attributes to the control prepared with shortening (Lim et al., 2017).

Pehlivanoglu et al. (2018b) formulated cakes with water-based-wax oleogels. The oleogel samples were prepared

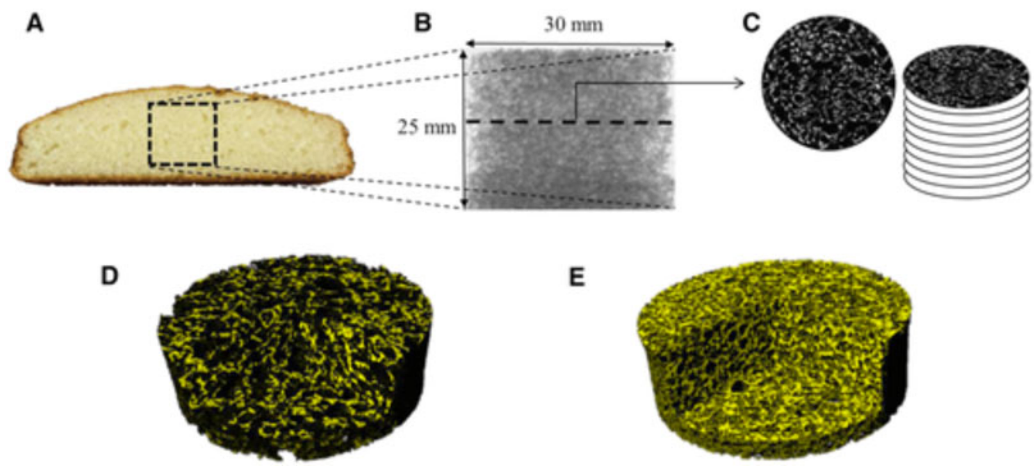

Figure 5. Micro-CT images of cake crumbs containing different ratios of shortening and oleogels ((A) cross-section of cake, (B) shadow X-ray image, (C) a series of reconstructed 2-dimensional slice images, (D) 3-dimensionl image of the control cake, and (E) 3-dimensional image of the 100% oleogel cake [the black areas are void spaces]). Reproduced from Kim et al. (2017) with the permission from the publisher.

using different percentages of high oleic sunflower oil, cotton seed oil, and blend fat and then they were used in the cake formulations. The most acceptable cake was prepared with oleogel containing high oleic acid sunflower oil and cotton seed oil at equal amounts (50/50). However, the authors mentioned that oleogel formulations significantly influenced the quality characteristics of the end product and it might be possible to produce healthier products are rich in unsaturated fatty acids. Giacomozzi et al. (2018) produced oleogels from a commercial mixture of monoglycerides and high oleic sunflower oil and evaluated them as fat replacers in muffins. The authors tried to optimize the oleogel formulation based on a three factors Box-Behnken design. Then, muffins were prepared with optimized oleogels. Replacement of commercial margarine with the optimized oleogels in muffin formulation provided a greater spreadability and a higher specific volume. The results of this study revealed that the replacement of commercial margarine with the optimized oleogels in muffin formulation offered similar hardness values and more connected and homogeneous crumb structures to oleogel containing muffins as compared to shortening containing muffins. It is interesting to note that oleogel containing muffins showed a reduction of oil migration of around 50% respect to the shortening containing muffin after 10 days of storage. Thus, in addition to reduction in saturated fat content, oleogels provided high oil binding capacity to this sweet baked product.

Although, the studies available in literature have showed that utilization of various forms of oleogels in bakery products has gained a significant interest; application of oleogels in gluten free products is extremely limited. It is well known that celiac patients should follow gluten-free diet through their lifespan and thus, development of gluten-free alternative products having healthier nutritional profiles plays a critical role for celiac patients as the number of celiac patients is rising. Celiac patients may be exposed to excessive consumption of total fats and saturated fats since many prepackaged gluten-free products contain more fat (almost twice), sugar or salt (depending on product type) than their conventional equivalents (Demirkesen and Mert, 2019). Furthermore, diet of celiac patients was hyperproteic and hyperlipidic and also contains inadequate amounts of carbohydrates, minerals such as iron and calcium, and also fiber. In addition, metabolic imbalance is another common problem seen in celiac patients due to lack of sufficient intake of essential fatty acids. Because of their diet, celiac patients especially children who are more likely to eat bakery products like cakes, cookies and biscuits are exposed to an increased risk of overweight/obesity. In one of our latest study, we evaluated oleogel and oleogel/shortening blends in gluten free aerated products to produce gluten free products having low saturated fat content. For this purpose, we used beeswax as the organaogelator because of its widespread availability and better functional ability. Similar to our previous studies, combinations of oleogel and shortenings were prepared using a custom-made pilot scale crystallization unit. The obtained material then was used in gluten-free cake formulations. The cake batter and baked cake samples were evaluated in terms of gas holding ability, textural, rheological, and structural properties. The result of the fatty acid combination of samples indicated that shortening was found to be rich in palmitic acid (16:0) as palm and palm kernel oil fractions are commonly applied for production of shortenings. It is important to note that such palm-based shortenings play critical role in air holding ability of batters since palm-based shortenings are known to form β' polymorphic forms that provide better in air stabilization than other crystal structures. Such crystal structures are relatively small and they can hold a larger amount of liquid oil in the crystal network resulting in formation of a glossy surface and a smooth texture. Consequently, they can provide better performance than that of plastic fats or liquid oils in cake batter. As aforementioned, beeswax has long chain fatty acids that are esterified to fatty alcohols and also other substances such as very long chain hydrocarbons, ketones, fatty alcohols, acylglycerols, and sterol esters. Thus, the blends of beeswax with sunflower oil resulted in 5% increase in the amount of saturated fatty acids. In case of gluten free formulations, the role of shortening becomes more important since gluten-free formulations are prone to staling more rapidly. Solid fat content of shortenings gives information about aeration ability of batters.

The result of SFC analysis indicated that oleogel containing 10% beeswax had considerably lower solid fat ratio than shortening. Furthermore, the blends of beeswax with shortening led to incremental increase of the solid fat and further series samples had wide range of SFC values and iodine values. The overrun values showed that at the beginning of mixing the batters prepared with oleogel containing 10% beeswax entrapped air bubbles in a faster rate compared to shortening that could be related to lower viscosity of the oleogel containing 10% beeswax containing batter. Conversely, as the mixing time continued, higher overrun values obtained from shortening containing batter. Higher SFC values of shortening resulted in stabilization of air bubbles in the batter and this result might be contributed to the role of *β*' polymorphs in shortening. Thus, the elevated levels of shortening in the blends led to higher overrun values. In general, the overrun results showed that a certain level of shortening is necessary for entrapment and stabilization of air bubbles. Bubble size distribution curves were negatively skewed and unimodal but as the shortening amount decreased mean size of the bubble became slightly smaller.

According to rheological measurements, to obtain space-filling network the amount crystal particles (SFC) should above a certain threshold value, thus more elastic properties could be obtained from batters. The quality parameters of cake samples indicated that porosity and specific volume of the samples were also reduced with complete replacement of the shortening with beeswax oleogel, but comparable quality parameters with control products that containing only shortening could be obtained with 45%, 30%, and 15% replacement of the shortening with beeswax oleogel. Overall, the results of our study showed that gradual replacement of shortening with oleogels have potential for partial reduction of saturated fat without chancing physical properties of luten free aerated products while providing celiac sufferers more alternatives in their diet.

Conclusions

The importance of limiting of saturated fatty acid intake and also the removal of trans-fatty acids from the diet have been documented in literature. Shortening as the essential component of bakery products affects dough structure and the desired final product attributes. Therefore, the replacement of shortening creates a big challenge in bakery problems. Recently, it has been shown that drawbacks related to the lack of shortening in bakery goods have been overcome by the application of oleogels. Considering critical roles of shortening, the replacement of shortening, conversely, creates a big challenge in case of bakery problems. The interactions between oil type and oleogelator type and oleogelator concentrations have been evaluated for different bakery products. The results of rheological measurements showed that incorporation of candelilla wax to canola oil provided solid-like properties to oleogels and the low viscosity of the oleogels at the baking temperature had a positive role in the expansion and collapse of the cookies during baking. In another study, the effects of hazelnut oil-beeswax and hazelnut oil-sunflower wax oleogels on quality of cookie samples were found to be similar with that of shortening. The potential applications of two different oleogels (made with candelilla and carnauba wax and sunflower oil) have also been employed to produce cookies. In another study, the effects of oleogels made with different types of different oils (olive oil, soybean oil, and flaxseed oil) and different waxes (sunflower wax, rice bran wax, beeswax, and candelilla wax) on cookie formulations was examined and it has been demonstrated that cookies prepared with oleogels had similar quality parameters with that prepared with shortening. In another study, candelilla or carnauba wax oleogels was found to be not as effective as solid fat in forming short dough under mixing conditions. Therefore, the functionality of the oleogels was found to be not sufficient to obtain the similar quality with shortening containing ones. It was stated that partial replacement of shortening with oleogels provided much more acceptable dough and cookie characteristics than total replacement.

In case of cake samples, among rice bran wax, beeswax, and candelilla wax; beeswax oleogels were found to be the most effective in producing nutritionally superior cakes with comparable quality attributes to the shortening cakes. The other studies demonstrated the potential of oleogels (canola oil-carnauba wax oleogels, grape seed oil, and candelilla wax) to produce cakes with lower levels of saturated fatty acids without quality loss when they replaced with shortening. The functionality of oleogel samples prepared using shellac or hydrocolloids such as hydroxypropyl methylcellulose, methyl cellulose, xanthan gum was also found to be effective as a shortening alternative for cake products. Recently, the partial replacement of the shortening with beeswax oleogel also showed a potential for reduction of saturated fat without chancing physical properties of gluten free aerated products. This might provide celiac sufferers more alternatives in their diet.

Studies about oleogels applications in bakery products have received an increased attention from the food industry. However, there are still some challenges that need to be addressed. It has been observed that due to irreversible structural breakdown under dough mixing conditions, oleogels may quickly lose their solid like structure as a result of shear forces. Conversely, oleogel/shortening blends can withstand to shear. Thus, in future work, the selection of the right kind of structuring agents, which can withstand the mixing and other processing conditions and reflecting the right functionality should be determined. Although, the research performed in the literature reflects the potential of oleogels as shortening replacer in bakery products, more detailed studies on oil structuring is also necessary for further optimization of oleogels to match quality characteristics of commercial shortening containing bakery products.

Disclosure statement

The authors declare that they have no conflicts of interest

ORCID

Ilkem Demirkesen http://orcid.org/0000-0003-1872-5838

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