Chapter 26
Edible Applications

Martina Dominguez and María Elena Carrín

Abbreviations

AA	Adipic acid
BS	β-sitosterol
BW	Beeswax
CB	Cocoa butter
CLW	Candelilla wax
CM	Commercial margarine
CRW	Carnauba wax
DG	Diglycerides
EC	Ethylcellulose
ERCA	Esterified rice flour with citric acid
FAP	Fatty acid profile
GO	γ-Oryzanol
HF	Hard fat
HFM	High-fat margarine
HIU	High intensity ultrasound
HO	Hazelnut oil
HOSO	High oleic sunflower oil
HPMC	Hydroxypropyl methylcellulose
LC	Lecithin
MG	Saturated monoglycerides

M. Dominguez · M. E. Carrín (✉)
Departamento de Ingeniería Química, Universidad Nacional del Sur (UNS), Bahía Blanca, Argentina

Planta Piloto de Ingeniería Química – PLAPIQUI (UNS-CONICET), Bahía Blanca, Argentina
e-mail: mdominguez@plapiqui.edu.ar; mcarrin@plapiqui.edu.ar

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MUFA	Monounsaturated fatty acids
O/W	Oil-in-water
OBC	Oil binding capacity
PGE	Polyglycerol esters
PS	Phytosterols
PUFA	Polyunsaturated fatty acids
RBW	Rice bran wax
SFA	Saturated fatty acids
SFC	Solid fat content
SFW	Sunflower wax
SLW	Shellac wax
SMS	Sorbitan monostearate
SSL	Sodium stearyl lactate
STS	Sorbitan tristearate
TFA	*Trans* fatty acids
UFA	Unsaturated fatty acids
UMG	Unsaturated monoglycerides
VOO	Virgin olive oil
W/O	Water-in-oil
XG	Xanthan gum
ΔE	Total color differences with respect to the control

26.1 Introduction

Advances in the knowledge of the harmful effects of some food components on health are driving the demand for healthier food products from different sectors of society. Fats are key ingredients in a wide variety of foods, performing some technological and sensory functions in defining desirable food properties, contributing to their flavor, lubricity, texture, stability, and shelf life and to consumer satiety [1–3]. Traditional, stable, and relatively inexpensive fatty products used to obtain these characteristics, such as butter, margarines, and shortenings, are mainly composed of saturated fatty acids (SFA) or mixtures of SFA and industrially produced *trans* fatty acids (TFA) [4–6]. However, overconsumption of both SFA and TFA has been claimed to cause some serious health concerns [3, 7–10]. Therefore, recommendations by international organizations emerged to eliminate TFA provision through food [11], as well as to decrease SFA consumption to values of at most 10% of total energy needs [12]. In addition, consumers are increasingly expected to demand not only healthy and natural food but also ethical and sustainable food production systems, according to the United Nations Sustainable Development Goals [13].

To meet these demands, the need for lower fat or improved quality products led industries and scientists to search for ingredients that could replace TFA and at least

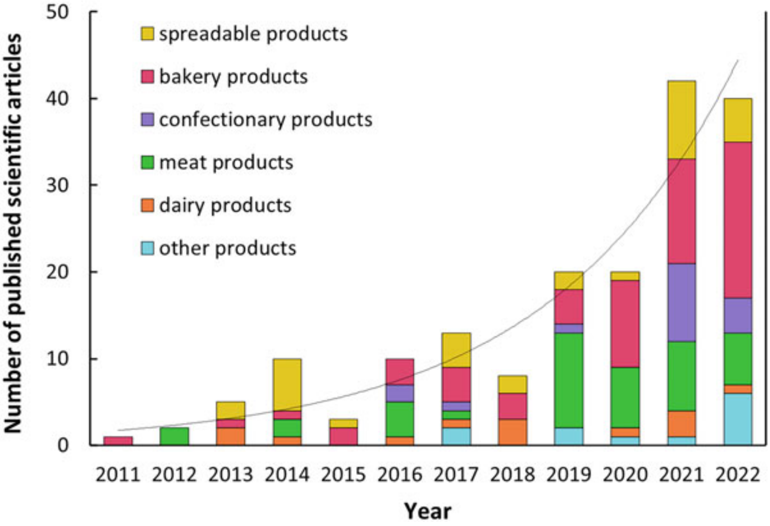

Fig. 26.1 Trend over time of different categories of oleogel-based system food applications. Bars represent the annual data and solid line denotes their tendency. Data were collected from Scopus-Elsevier by searching oleogels or organogels food applications (including each of the specified applications) (update to February 17, 2023)

reduce SFA use. However, this involves a major development and innovation effort in the research and industry sectors to mimic the functionalities that hard fats (HF) provide to each of the different products where they are used. As has been introduced in previous chapters, this requirement has been addressed, among other proposals, through the structuring of vegetable oils with a high content of unsaturated fatty acids (UFA). For this purpose, various gelling agents or structurants have been tested—waxes, HF, lecithin (LC), ethylcellulose (EC), phytosterols (PS), saturated monoglycerides (MG), and diglycerides (DG), or emulsifiers with biopolymers, including proteins and polysaccharides—requiring different preparation methodologies. Therefore, over almost the last decade, some oleogel-based systems have demonstrated their promising applicability as substitutes for fats conventionally used in a variety of foods, which can be grouped into broad categories (Fig. 26.1). Replacement proposals were initially moderate and focused mainly on spreadable products. This trend was changing and currently the most evaluated reformulations are also based on bakery and meat products. Additionally, new technological applications have been emerging lately.

Nevertheless, these systems have still limited commercial-level implementation in the food industry due to some technological challenges arising from process adaptation or consumer sensory demands [4, 14]. In addition, the requirement to use ingredients suitable for human consumption has to be met. For instance, although there are some doubts about the food use of certain wax types, legislation is moving positively in this regard [15, 16].

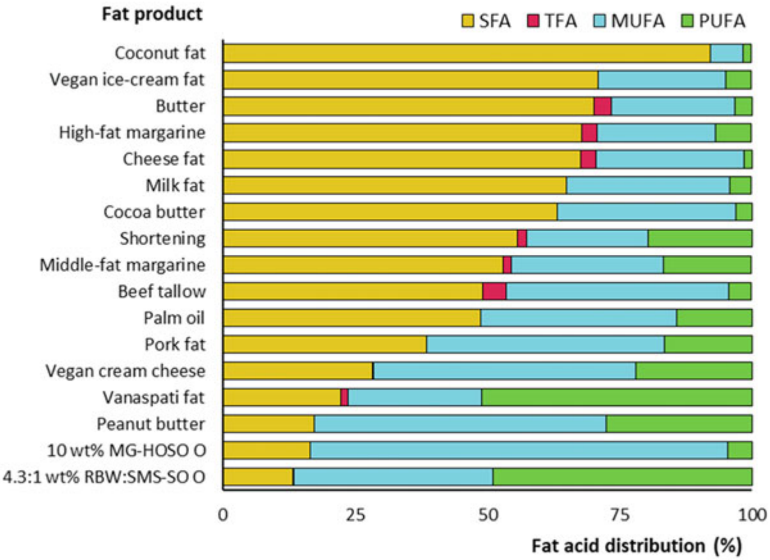

Fig. 26.2 Fatty acid distribution—SFA, TFA, PUFA, and MUFA to saturated, *trans*, polyunsaturated, and monounsaturated fatty acids, respectively—in some commercial fats and oleogel-based systems. *MG* saturated monoglycerides, *HOSO* high oleic sunflower oil, *O* oleogel, *RBW* rice bran wax, *SMS* sorbitan monostearate, *SO* sunflower oil. (Data were collected from different sources [14, 16–24])

In nutritional terms, replacing all or part of the HF with oleogel-based systems significantly impacts the lipid profile of food products, and this will be determined not only by the composition of that system (base oil and other added compounds such as structurants and emulsifiers) but also by the substitution level [14]. Particularly, oleogel lipid profile will be close to that of the base oil used, especially when it is relatively low in structurant. Thus, oleogel-based materials using oils high in monounsaturated fatty acids (MUFA)—MUFA >50%, such as high oleic varieties of sunflower and safflower, canola, hazelnut, peanut, and olive oils—or oils high in polyunsaturated fatty acids (PUFA)—PUFA >50%, such as corn, flaxseed, sunflower, soybean, and walnut oils—have an improved fatty acid profile (FAP) compared to the fats they are intended to replace, as can be observed in Fig. 26.2.

In view of the abovementioned, this chapter explores progress in research carried out to evaluate the suitability of oleogel-based systems for their application in different food products, focusing especially on lipid profile improvement, but also including other functional or technological issues. Also, it attempts to highlight the challenges faced by the food industry in making oleogel applications effective and the prospects for the future.

26.2 Spreadable Products

A variety of fatty products are usually ingested as breakfast spreads or manufactured as spreadable products to be post-processed into other foods. These products contribute undesirable levels of SFA and TFA to the diet, which makes oleogel-based systems an attractive replacement option. A large number of them have been evaluated as alternative spreads, mainly as margarine or shortening substitutes (Table 26.1).

Margarine is commonly used as a breakfast product or as an ingredient in cooking and baking preparations, being a butter substitute in many recipes. It is formed by uniformly dispersing small water droplets in a highly saturated fat phase, thus constituting a stable solid form of a water-in-fat emulsion. Developing stable water-in-oil (W/O) emulsion-based products with reduced SFA and without TFA is the main constraint to overcome. Different oleogel-based systems have been used to emulate margarine, with variations in the components and their proportions and in the preparation method—emulsions from pre-formed oleogels or directly from the molten materials. Although some product differences have been assigned to the preparation method [29], no systematic comparison between both methodologies was found to justify those results.

Waxes from different origins have been the most evaluated structurants for margarine production. Considering that sunflower wax (SFW), rice bran wax (RBW), and candelilla wax (CLW) efficiently structured soybean oil even at low concentrations, the corresponding oleogels were tested in a high-fat (80%) margarine (HFM) [27]. Among them, SFW-based margarines were the best option, having comparable firmness to margarines formulated using a mixture of hydrogenated and conventional soybean oil, a commercial margarine (CM), and some spreads. It is to be noted that the UFA:SFA ratio was improved from 2.5–4.5 to 6 using SFW oleogels. Similar texture results were obtained using other 13 oils [28]. Final product properties were also modified by using waxes or oils from different suppliers, origins, or processing, probably related to minority component presence in dissimilar proportions. Promising results were reported using SFW and RBW to structure hemp seed oil [31]. Using 3 wt% wax in emulsions was enough to achieve commercial spread firmness. However, stick margarine firmness was not obtained even with 7 wt% wax. Similarly, an oleogel with 10 wt% beeswax (BW) was satisfactorily used to replace palm and hydrogenated palm oil in the formulation of a medium-fat margarine (70% fat)—with 28% SFA and 80% TFA reductions—[26]. Although the oleogel-based product had lower solid fat content (SFC) and higher melting point than the control, rheological and textural characteristics were similar. Rapeseed oil was successfully gelled by shellac wax (SLW) and used to formulate emulsifier-free W/O emulsions at different water:oil proportions [46, 48]. Acceptable spreadable properties were obtained when emulating HFM (Fig. 26.3a1), achieving 80% SFA and 40% PUFA reductions and a 158% MUFA increase. However, emulsion stability was difficult to maintain when dealing with low-fat (<60%) products. Additionally, emulsifiers and cold storage were used to favor textural and

Table 26.1 Oleogel applications in spreadable products

Food product	System	Gelator (wt% in system)/ oil	Replaced fat (wt% replacement)	Reference
Margarine	Oleogel	MG (12)/vC-loaded corn	Margarine fat (100)	[25]
	Oleogel	BW (2.5–10)/n.s	Palm oil, partially hydrogenated palm olein oil (100)	[26]
	Oleogel	SFW, RBW, CLW (2–6)/soybean	CM fat (100)	[27]
	Oleogel	SFW (3, 5, 7)/various[a]	Margarine fat (100)	[28]
	Oleogel	CLW:BW (0–7:7–0)/ soybean	Monocomponent wax oleogel (100)	[29]
	W/O emulsion	BW (7)/corn	Margarine (100)	[30]
	W/O emulsion	SFW, RBW (3–7)/hemp seed	Margarine (100)	[31]
	W/O emulsion	MG:LC (22:8)/palm olein	CM (100)	[32]
	W/O emulsion	MG:DG:TG (31.2:42.3: 26.5)/tigernut	CM, butter (100)	[33]
	W/O emulsion	CLW:ICF:MG (3.3:6.1: 2.2)/HOSO	CM (100)	[34]
	W/O emulsion	CLW:FHPO:UMG (0.4–1:0.6–1.3:0.3–0.8)/ soybean	Margarine (100)	[35]
Mayonnaise	O/W emulsion	SFW:Tween20:SMS20 (1.5:2:0.05)/various[b]	Mayonnaise (100)	[36]
Shortening	Oleogel	MG (10.8, 12.4)/HOSO	Low-fat CM (100)	[37]
	Oleogel	MG (6.6, 8.2)/HOSO	Low-fat CM (100)	[38]
	Oleogel	BW, SFW (3, 7, 10)/ olive	Breakfast margarine (100)	[39]
	Oleogel	RBW (5)/rice bran	Margarine, beef tallow (100)	[21]
	Oleogel	RBW:SMS (2–5:1–3)/ sunflower	Vanaspati fat (100)	[23]
	Oleogel	EC:TMS (4:1)/palm stearin:soybean (23:77)	Shortening (100)	[40]
Spread	Oleogel	MG (3, 7, 10)/pomegranate seed	CM fat (100)	[41]
	Oleogel	MG, CRW (3, 7, 10)/ VOO	Breakfast CM fat (100)	[42]
	Oleogel	BW, SFW (5)/VOO, HO	Breakfast CM fat, butter (100)	[43]
	Oleogel	BW, SFW, SLW (1, 3, 5)/*n.a*	Tahini emulsifier (100)	[44]
	Oleogel	SFW (10)/VOO	n.s	[45]
	Oleogel	SLW (6)/rapeseed	n.s	[46]
	Oleogel	WSW (8)/VOO	n.s	[47]

(continued)

Table 26.1 (continued)

Food product	System	Gelator (wt% in system)/oil	Replaced fat (wt% replacement)	Reference
	W/O emulsion	BW, CLW, RBW, SFW, HCO (0.5–2)/peanut butter	Peanut butter (100)	[16]
	W/O emulsion	SLW (5.5)/rapeseed	n.s	[48]
	W/O emulsion	EC:MG (7:0.5, 7:1)/high oleic safflower	Spread CM (100)	[49]
Chocolate spread	Oleogel	MG, BW, PW (5)/pomegranate	Palm oil (50)	[50]
	Oleogel	SLW (6.8)/rapeseed: palm	Oil binder (100), palm oil (~27)	[48]
	W/O emulsion	MG (20)/corn	Oleogel (45, 50, 55)	[51]
	Emulsion-templated oleogel	HPMC:XG (1.62:0.97)/sunflower, olive	Coconut fat (50, 100)	[52]
	Dispersion	Cellulose fibers (5–40)/rapeseed	Palm oil (100)	[53]

[a] Almond, canola, corn, flaxseed, grapeseed, olive, peanut, pumpkin seed, safflower, sesame, soybean, sunflower, and walnut

[b] Groundnut, sunflower, soybean, sesame, mustard, rice bran, coconut, and palm

BW beeswax, *CLW* candelilla wax, *CRW* carnauba wax, *DG* diglycerides, *EC* ethylcellulose, *FHPO* fully hydrogenated palm oil, *HCO* fully hydrogenated cottonseed oil, *HO* hazelnut oil, *HOSO* high oleic sunflower oil, *HPMC* hydroxypropyl methylcellulose, *ICF* interesterified commercial fat, *LC* lecithin, *MG* saturated monoglycerides, *n.a* not applicable, *n.s* not specified, *PW* propolis wax, *RBW* rice bran wax, *SFW* sunflower wax, *SLW* shellac wax, *SMS* sorbitan monostearate, *TG* triglycerides, *TMS* triglyceryl monostearate, *UMG* unsaturated MG, *vC* vitamin C, *VOO* virgin olive oil, *XG* xanthan gum, *W/O* water-in-oil, *WSW* whale spermaceti wax

rheological properties and stability of margarines based on BW-corn oil oleogels—diminishing 56% SFA and increasing 26% PUFA—[30]. Although some differences in thermal properties were detected between reformulated and commercial products, sensory properties were not examined to confirm or correct the reformulation.

MG have also been used to prepare oleogels for margarine production. After complete fat content replacement of HFM with an MG-corn oil oleogel, lower values of firmness, SFC, and TFA were obtained in comparison with commercial butters [25]. However, oleogel-based margarine had the highest values of adhesiveness, spreadability, and UFA content. Interestingly, although the appearance of the oleogel-based margarine was visually more translucent than that of the butters, consumers rated all samples with high appearance scores declaring their willingness to try or even buy that product.

Some structurants have been tested in combination, either in binary or multicomponent mixtures. However, a few of these systems have been evaluated in margarine formulations, finding that some of their important properties could be tailored by structurant proportions. CLW-BW oleogels were able to form HFM with

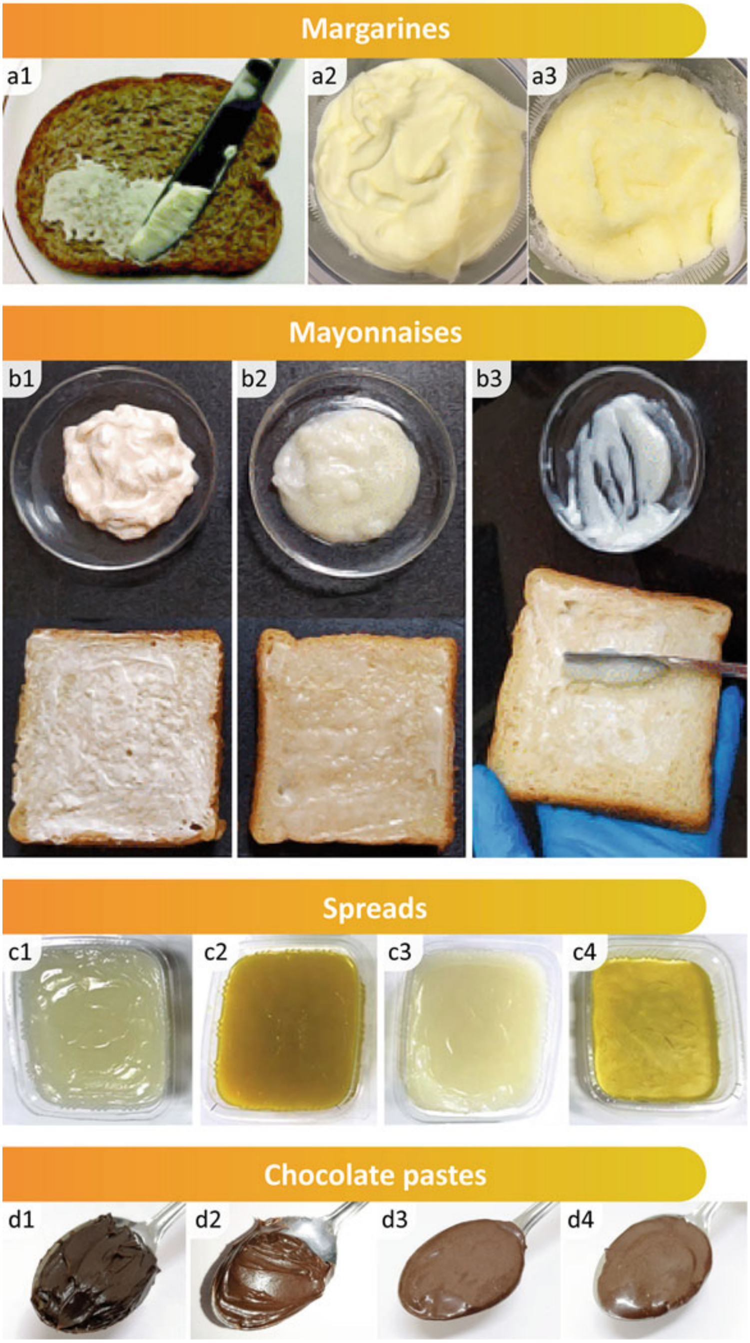

Fig. 26.3 Appearance of spreadable products elaborated with different oleogel-based systems: (**a**) margarines from (a1) shellac wax oleogel into a high-fat emulsion, reproduced from [46] with permission from The Royal Society of Chemistry, and tigernut glycerolysis product stored at refrigerated conditions for (a2) 1 week and (a3) 10 months after sample preparation, reproduced

improved or similar textural characteristics compared to that obtained using only one wax type [29]. These binary wax-based margarines had lower melting points and residual SFC at near body temperature, thereby yielding products with features closer to CM. However, other properties required a CLW:BW ratio reduction. An HFM was also formulated using a mixture of CLW, MG, and an interesterified commercial fat in high oleic sunflower oil (HOSO) [34]. Although differences in microstructures and melting curves were detected between the reformulation and CM, the former yielded a softer product of similar color but more resistant to temperature fluctuations than CM. Even with a high unsaturation proportion, the oleogel-based margarine showed acceptable oxidative stability. However, this reformulated margarine could not reach the sensory scores assigned to CM, potentially due to a residual waxy taste. Surprisingly, consumer intention to buy them was similar, suggesting that other attributes should be considered when looking for relationships between product properties and consumer reactions. Low-fat (35%) and middle-fat (60%) margarines were also reformulated with CLW and unsaturated monoglycerides (UMG) in soybean and fully hydrogenated palm oil [35]. Margarines with lower water content showed higher hardness and thermal stability and lower spreadability. Oleogelation made it possible to obtain different margarines with improved PUFA (3–21%), reduced SFA (10–33%), and practically TFA free. MG and LC, besides water, were studied to produce a low-fat margarine with CM-like mechanical properties [32]. An optimized product was obtained with respect to its structural properties, but using a high structurant proportion (30 wt% LC + MG) and 28 wt% water. Thus, although palm oil content was reduced (~24%), SFA increased ~43% because of reformulation. An EC-MG gelled W/O emulsion had higher elasticity and thermal stability than a conventional emulsion (without EC) or EC-MG oleogel [49]. Its ability to maintain MG at the droplet interface could be responsible for increased emulsion stability at higher MG concentrations. In comparison to low-fat CM, the gelled emulsions had lower elasticity. Therefore, higher concentrations of mixed emulsifiers could be a promising strategy to reach CM elasticity, without adding high proportions of SFA or using TFA.

Promising oleogels resulted from the products obtained by unsaturated oil enzymatic glycerolysis [33]. This oleogel type showed satisfactory results to substitute palm and hydrogenated oils in margarine production—plasticity similar to CM and butter and high storage emulsion stability (Fig. 26.3a2, a3)—highly improving UFA

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Fig. 26.3 (continued) from [33] with permission from Elsevier; (**b**) mayonnaises from (b1) commercial product and (b2) SFW oleogel-based emulsions and (b3) its application on bread, reprinted with permission from [36] Copyright (2021) American Chemical Society; (**c**) spreads using oleogels from (c1) beeswax (BW)-hazelnut oil (HO), (c2) BW-virgin olive oil (VOO), (c3) sunflower wax (SFW)-HO, and (c4) SFW-VOO, reproduced from [43] with permission from The Royal Society of Chemistry; and (**d**) chocolate pastes using water:oleogel-based emulsions at ratios of (d1) 0:100, (d2) 45:55, (d3) 50:50, and (d4) 55:45, reproduced from [51] with permission from Elsevier.

(110%). It also exhibited a more suitable melting curve than that usually achieved by wax-based oleogel margarines.

Mayonnaise is based on an oil-in-water (O/W) emulsion with a large proportion of oil, which has a characteristic highly viscous and shear-thinning behavior. Looking for conventional mayonnaise alternatives, oleogel-based emulsions were prepared using different vegetable oils structured with SFW and some emulsifiers [36]. Although each oil contributed its own characteristic color to the emulsions formed, all presented a visual mayonnaise-like appearance. Varying oil unsaturation degree significantly affected the product strength, SFC, and oil binding capacity (OBC), while not affecting its microstructure. As the unsaturation degree increases, OBC increases, making emulsions of highly unsaturated oils capable of substituting commercial mayonnaise (Fig. 26.3b).

Shortening is considered any fat that, at room temperature, remains solid and is generally used to make a wide variety of food products. Oleogels are usually presented as a direct healthier replacement for shortenings, although achieving their specific properties is a challenge. In addition to improving FAP, different oleogels have been tested to prevent the formation of water-containing systems. This last point confers oleogels a great advantage in terms of their chemical and physicochemical stability. MG-HOSO oleogels were produced to resemble the properties of a low-fat CM [37, 38, 54]. Both processing conditions and MG concentration (without exceeding control SFA) were optimized to achieve the desired properties, which were maintained unchanged for at least 3 weeks. Oleogels from BW or SFW were formulated to mimic breakfast margarine [39]. Although BW oleogel had thermal properties closer to those of the control, using different concentrations of each wax allowed to reach target textural properties—which remained stable for at least 3 months. RBW-rice bran oil oleogels have also been successfully formulated as substitutes for baking margarine and even beef tallow [21]. These products were used in a digestibility assay, showing that although the oleogel-based diet—highly enhanced in FAP—did not have anti-obesity effects, it did provide some other health benefits, confirming the postulates used in favor of oleogels. RBW was also used in combination with sorbitan monostearate (SMS) to structure sunflower oil as a low-saturated fat substitute for vanaspati, a popular fat in some countries [23]. Oleogel-based vanaspati, presenting nearly 40% SFA reduction, had rheological properties similar to commercial samples, but not some thermal properties.

Spreads are usually pastes that can be applied and adhere properly to food surfaces. Oleogel-based spreads have been widely formulated using virgin olive oil (VOO), based on the benefits that its consumption can bring not only for its FAP but also for its minority components. MG-VOO oleogels showed higher OBC and thermal properties closer to breakfast CM than carnauba wax (CRW)-VOO oleogels, both generating major UFA increments [41, 42]. However, some margarine textural properties were not achieved by any of the oleogels, nor with MG oleogel which retained control SFA level. Sensory properties and consumer acceptance of oleogels from VOO or diacetyl-enriched hazelnut oil (HO) and two types of waxes were evaluated as spreadable fats [43]. Both types of oleogels showed acceptable appearance and sensory attributes, regardless of the wax type used. Although the sample's visual appearance was quite remarkable (Fig. 26.3c), more than half of the consumers expressed their intention to buy these substitutes.

Spices added to oleogels provide antioxidant bioactive compounds. SFW was used to structure VOO enriched with thyme and cumin spices [45]. Spices did not affect gel formation, gel thermal stability, or gelation time, but generated intermediate shear-stable oleogels. Moreover, whale spermaceti wax-VOO oleogels enriched with ground red pepper and turmeric allowed the obtention of spread-type products with satisfactory quality indexes [47]. As expected, VOO and spices contributed to the oleogel color and aromatic profile; however, the spice-enriched oleogels were liked by consumers.

Through gelling, waxes have been highly efficient in improving oil separation in some products. For instance, to reformulate tahini paste, SFW, SLW, and BW were tested as oil stabilizers compared to the commercially used emulsifier, hydrogenated palm stearin [44]. Using SFW and SLW, oil migration was significantly reduced and products similar to the control were obtained, even with improved FAP. Liquid oil in peanut butter spreads is also usually stabilized by a high-SFA material. OBC, firmness, and 6-month oil stabilization were improved by wax oleogelation, mainly with SFW [16].

Chocolate spreads are constituted by a continuous phase of commonly solid fat—such as cocoa butter (CB), palm oil, or coconut oil—into which another phase is dispersed. Reformulation of chocolate spreads lowering their SFC can be especially challenging, as saturated fats significantly support some of the most important properties required in this type of product—creamy texture, glossy appearance, taste, flavor, and mouth-melting behavior—[51]. A chocolate spread was reformulated by replacing oil binder and palm oil with SLW-rapeseed oil oleogel, obtaining a storage stable oleogel-based paste and reducing SFA by ~24% [48]. Oleogels produced from pomegranate seed oil and MG, BW, or propolis wax were also used to reformulate chocolate spreads partially replacing palm oil and, therefore, lowering SFA by at least 39% [50]. Product mechanical parameters were modified depending on the structurant used, with the lowest and highest values found for propolis wax and MG, respectively. However, paste storage caused hardness to vary, tending toward more similar values. Additionally, oleogels from olive or sunflower oil and hydroxypropyl methylcellulose (HPMC) and xanthan gum (XG) were used to reformulate chocolate spreads [52]. Total coconut butter replacement led to inhomogeneous materials, while structures similar to the control were obtained by partial replacement—even strongly reducing SFA. Moreover, when sunflower oil oleogels were used in partial replacement, a sensory evaluation similar to the control was reached. A bamboo fiber-rapeseed oil dispersion—without heating or emulsifying—was used to produce a chocolate spread with good rheological properties, high thermal stability, and healthier nutritional qualities than the palm oil-based spread [53].

The expected mouth-melting behavior of chocolate pastes can be difficult to achieve when high proportions of oleogels are used in reformulations. In this context, a gelled W/O emulsion from an MG-corn oil oleogel was used to formulate low-fat spreads [51]. By using a 45:55 water:oleogel-based emulsion, an acceptable product was obtained, with good sensory scores and rheological and textural properties similar to an oleogel-based chocolate paste (Fig. 26.3d).

26.3 Bakery Products

Fat content reduction is a crucial aspect in bakery product formulation, considering all the characteristics that fats provide to these products during baking, storage, and consumption. Among others, hardness, fracturability, spread ratio, fat migration, and surface color are important product quality attributes because they impact consumer acceptability and willingness to purchase. Table 26.2 shows several examples of different oleogel-based systems proposed for the reformulation of bakery products by substituting traditionally used shortenings and margarines.

Fat and water have an important role in the development of gluten tridimensional structure in bakery products. However, not all of these products require the same gluten net strength. Some bakery goods are characterized as short-dough products—cookies and biscuits—while other products need extended gluten network building—such as bread. Therefore, not only fat/water proportion but also fat type and its distribution in dough must be carefully selected and generated to obtain the desired properties [77, 88]. When baking products based on conventional fats, it is necessary to provide a relatively high SFC to ensure proper dough lubrication, aeration, and hardness and consequently to generate areas strong enough to contain air bubbles during cooking to finally obtain products with appropriate characteristics [77, 78, 85, 87, 88]. Different behaviors have been reported using oleogel-based systems instead of conventional fats. The presence of emulsifiers in the fat phase has been recognized as a key factor to adequately disperse this phase on the dough hydrophilic ingredients, not only disturbing gluten formation but also increasing starch gelatinization temperature and prolonging gas retention time [77].

Biscuits and cookies, usually with about 25% fat, should be formulated from smooth, uniform, and plastic doughs [78]. During ingredient mixing, initial emulsified creams from sugar and commercial fats are typically harder than those from oils and oleogels, but after flour inclusion, the desired dough properties can be reached. However, oil-based creams present difficulties in achieving appropriate air entrapment and adhesion during mechanical working, generating hard cookies [78, 87, 88]. When oil was previously structured, cookie dough hardness approached that obtained with shortenings, while dough extensibility decreased. Compared to the oil-based system, oil structuring by CRW or CLW improved dough air-holding capacity and cookie spread ratio. Nevertheless, shortening-based cookie properties were not fully achieved by replacing shortening with oleogels with up to 5 wt% waxes [88], but they were reached by partial replacement with CLW oleogel while improving FAP [87]. Additionally, a certain waxy aroma was reported after cooking, which could be a negative factor for consumers and, therefore, deserves to be evaluated [88]. Moreover, oil-based biscuits have shown fat migration, which was

Table 26.2 Oleogel applications in bakery products

Food product	System	Gelator (wt% in system)/oil	Replaced fat (wt% replacement)	Reference
Bread	Oleogel	MG, RBW (10)/soybean	Shortening (100)	[55]
	Oleogel	SSL (9)/sunflower	Margarine (100)	[56]
	Oleogel	EC:TMS (4:1)/palm stearin: soybean	Shortening (100)	[40]
Bun	Emulsion-templated oleogel	HPMC:XG (1.6:1)/sunflower, olive	Margarine (100)	[57]
Sweet bread	Oleogel	CLW (10)/rice bran	Butter (25, 50, 75, 100)	[58]
	Oleogel, O/W emulsion	MG (2.7, 5)/sunflower	Palm oil oleogel, emulsion (100)	[59]
Cake	Oleogel	BW, SFW (5), BW:SFWh (2.5:2.5)/canola	Palm fat (100)	[60]
	Oleogel	CLW (5)/canola	Butter (25, 50, 75, 100)	[61]
	Oleogel	BW (10)/sunflower	Shortening (15, 30, 45, 60, 80, 100)	[62]
	Oleogel	CRW (10)/canola	Shortening (25, 50, 75, 100)	[63]
	Oleogel	RBW, BW, CLW (10)/ sunflower	Shortening (100)	[64]
	Oleogel	MG:BW (7:3, 3:7, 5:5, 10:0, 0: 10)/HOSO	Margarine (100)	[65]
	Oleogel	CRW:AA (2:4, 6:0)/soybean	Shortening (50)	[66]
	Oleogel	EC:AA (2:4, 6:0)/soybean	Shortening (50)	[67, 68]
	Oleogel	BS:GO (3.2:4.8), SSAP (12)/ menhaden, SL	Shortening (100)	[69]
	Oleogel, W/O emulsion	CRW (5)/cotton seed, HOSO, blend fat	Shortening (100)	[70]
	W/O emulsion	SLW (5.5)/rapeseed	Margarine (100)	[48]
	O/W emulsion oleogel	Canola proteins (8)/canola	Shortening (100)	[71]
	O/W emulsion oleogel	OSA-KGM (6)/peanut	Margarine (100)	[72]
	O/W emulsion oleogel	XG:GG (1.7:1.7)/sunflower		[73]

(continued)

Table 26.2 (continued)

Food product	System	Gelator (wt% in system)/oil	Replaced fat (wt% replacement)	Reference
			Shortening (25, 50, 75, 100)	
	O/W emulsion oleogel	Gelatin:BLP (2.2:0.4)/soybean	Margarine (100)	[74]
	Foam-templated oleogel	MG (0–10)/soybean	Butter (50)	[75]
	Foam-templated oleogel	Protein:XG (3.1:0.03)/canola	Shortening (100)	[76]
Cookie	Oleogel	MG, SSL (3–15), PGE, SMS (9–18)/corn	Shortening (100)	[77]
	Oleogel	MG (5), CLW (2, 3), RBW (2), BW (5), EC (8)/high oleic rapeseed	Palm oil (100)	[78]
	Oleogel	MG, BS (10), MG:BS (5:5)/soybean	Shortening (100)	[79]
	Oleogel	MG, CRW (10), BS:BW (2:8), BS:LC (12.8:3.2)/sunflower	Margarine (100)	[80]
	Oleogel	BW, SFW, RBW, CLW (8)/olive, soybean, flaxseed	Margarine (100)	[81]
	Oleogel	BW (6)/sunflower	Oil (100)	[82]
	Oleogel	BW (6)/sunflower	HF (100)	[83]
	Oleogel	BW, CLW, CRW (n.s)/TML	Shortening (100)	[84]
	Oleogel	BW, SFW (5)/hazelnut	Shortening (100)	[85]
	Oleogel	CLW (3, 6)/canola	Shortening (100)	[86]
	Oleogel	CLW (3, 6)/canola	Shortening (30, 60, 100)	[87]
	Oleogel	CRW, CLW (2.5, 5)/sunflower	Shortening (100)	[88]
	Oleogel	RBW (3–9)/soybean	Shortening (100)	[89]
	Oleogel	RBW, BW, CLW, CRW (3, 5, 7, 9)/corn	Shortening (100)	[90]
	Oleogel	EC (1.5)/MCT	Liquid oil (100)	[91]
	Oleogel	RBW:BF (4.5:0.5, 5.5:0.5)/sunflower	Butter (100)	[92]
	Oleogel, O/W emulsion	ERCA:BW (0–15:2)/soybean	Shortening (50)	[93]
	Oleogel, emulsion-templated or foam-templated oleogel	MG, BW, RBW, HPMC, SSL (6)/corn	Shortening (100)	[94]
	Oleogel, W/O emulsion	RBW (9)/rice bran		[95]

(continued)

Table 26.2 (continued)

Food product	System	Gelator (wt% in system)/oil	Replaced fat (wt% replacement)	Reference
			Margarine (100)	
	Bigel	CRW (5)/canola	Shortening (25–100)	[96]
	Bigel	BW (5)/canola	Shortening (100)	[97]
	Foam-templated oleogel	MG (0–10)/soybean	Butter (50)	[75]
	Emulsion-templated oleogel	TPE (3)/camellia	Butter (25, 50, 75, 100)	[98]
	Emulsion-templated oleogel	LC: Inulin (2:19)/VOO	Butter (20, 40, 50)	[99]
	Emulsion-templated approach + crosslinking	Chitosan: Vanillin (1:3)/canola	Shortening (100)	[100]
Cracker	Oleogel	MG, RBW (10)/soybean	Shortening (100)	[55]
Muffin	Oleogel	MG (6.6, 8.06)/HOSO	CM (100)	[38, 101]
	Oleogel	CLW (10), CLW:MG (7.5:2.5), CLW:BC (10:0.02), CLW:MG:BC (7.5:2.5:0.02)/sunflower	Shortening (100)	[102]
	Oleogel	CLW, SFW, BW (5)/rapeseed	Shortening (100)	[103]
	Oleogel	CLW (8)/grape seed	Shortening (25, 50, 75, 100)	[104]
	Foam-templated oleogel	HPMC (4)/sunflower	Shortening (25, 50, 75, 100)	[105]
Puff pastry	O/W emulsion	MG:SFA (9:1.8)/sunflower	CM (100)	[106]
	O/W emulsion	MG:CB (3:10)/VOO	CM (100)	[107]
Tart pastry	Oleogel	EC:MG (12:0, 6:6, 0:12)/avocado:olive (1:1)	Butter, shortening (100)	[108]

AA adipic acid, *BC* β-carotene, *BF* bamboo fiber, *BLP* bayberry leave proanthocyanidins, *BS* β-sitosterol, *BW* beeswax, *CLW* candelilla wax, *CM* commercial margarine, *CRW* carnauba wax, *EC* ethylcellulose, *ERCA* esterified rice flour with citric acid, *GG* guar gum, *GO* γ-oryzanol, *HF* hard fat, *HOSO* high oleic sunflower oil, *HPMC* hydroxypropyl methylcellulose, *LC* lecithin, *MCT* medium chain triglycerides, *MG* saturated monoglycerides, *n.s* not specified, *OSA-KGM* biopolymer from octenyl succinic anhydride and Konjac glucomannan, *O/W* oil-in-water, *PGE* polyglycerol esters, *SFA* saturated fatty acids, *SFW* sunflower wax, *SFWh* sunflower wax hydrolysate, *SL* structured lipids, *SLW* shellac wax, *SMS* sorbitan monostearate, *SSAP* sucrose stearate/ascorbyl palmitate, *SSL* sodium stearyl lactate, *TG* triglycerides, *TML* Tenebrio molitor larvae, *TMS* triglyceryl monostearate, *TPE* tea polyphenol ester, *VOO* virgin olive oil, *W/O* water-in-oil, *XG* xanthan gum significantly diminished by using oleogels [78]. Other studies have reported that cookies made with MG, BW, RBW, CLW, SFW, or SMS oleogels have shown hardness more similar to commercial fat-based products than those with CRW, sodium stearyl lactate (SSL), or polyglycerol esters (PGE) oleogels, even with similar SFA reduction [77, 78, 80, 81, 84–86, 90, 94].

Cookie textural properties depended strongly on the components structuring the oleogel—purity and composition—rather than on oleogel or dough properties [82, 83]. For instance, oleogels from unfractionated BW and different fractionated BW provided some variation in cookie hardness and organoleptic properties compared to those obtained with oil and butter. With little change in cookie appearance and spread ratio, RBW-corn oil oleogels, regardless of the use of crude or refined oil, also were suitable for replacing cookie fat [89]. Nevertheless, the use of unrefined oil in oleogels generated harder cookies [79, 89]. Although important differences have been described between the properties of oleogels based on different types of oils and structurants and the corresponding cookie dough properties, final cookie properties have not been affected in the same way. For instance, different wax oleogel-based systems led to cookies with comparable quality attributes to commercial fat-based cookies [81, 84]. In addition, CLW oleogels were the most similar to palm oil, but MG oleogels produced biscuits more similar to the control product [78]. Moreover, the inclusion of fibers in RBW oleogels reduced dough firmness positively impacting cookie texture parameters and approximating butter-based cookie properties [92]. However, differences in recipes and technological parameters, as well as component quality used, may have led to some of the reported differences in the indicated behaviors.

Looking for more generalized trends to guide cookie reformulation from a theoretical framework, the hardness of cookies reformulated with wax oleogels was more inversely related to SFC and β' crystalline form in the corresponding oleogels, in addition to their rheological parameters, than to crystal size [90]. Furthermore, when other emulsifiers were used (MG, SSL, PGE, and SMS), softer cookies were produced from high-viscosity oleogels using structurants with higher hydrophilic-lipophilic balance values, reflecting their greater ability to withstand processing conditions [77]. However, the hardness of these cookies was driven neither by the amount of crystals or SFC nor by the type of crystalline material in the oleogels, nor by their viscoelasticity, even during heating. This is a very interesting result that should be taken into account when considering oleogel formulation optimization, since increasing structurant concentration usually increases oleogel hardness, but this will not necessarily favor final cookie properties.

Cookie structure of similar hardness to that based on shortening proved to be of homogeneous porosity [77, 94]. Additionally, the increased cookie brightness has been related to a higher oleogel SFC, postulating that the mobility of some browning reaction reagents could be hindered by the higher SFC. Moreover, the generation of more fluid doughs during preparation tended to produce cookies that were more differentiated from conventional fat ones [94]. Some significant total color differences with respect to the control (ΔE) have also been found between reformulated and traditional cookies ($\Delta E > 3$), indicating that consumers would perceive such a change [78, 80, 94]. However, cookies reformulated with MG, RBW, SFW, and BW oleogels scored comparable or even higher than shortening-based cookies in terms of surface color or overall acceptability [85, 94]. Moreover, cookie dimensions and spread ratio were not modified after reformulating the recipe by replacing 50 and 100% of margarine with an emulsion from RBW oleogel [95]. However, less hard doughs and cookies and lighter colored cookies were obtained as fat replacement increased.

Multicomponent oleogels using β-sitosterol (BS)-BW and BS-LC produced doughs with hardness more similar to a margarine-based dough, in comparison to MG or CRW oleogel [80]. However, not only were these differences not maintained after baking, but also these structurant combinations generated cookies with a different hardness than conventional ones. Nevertheless, similar or improved cookie properties were produced using BS-MG oleogels instead of shortening—even diminishing 30% SFA—regardless of using crude or refined soybean oil [79].

Bigels in which oleogels were produced from canola oil and CLW or BW showed great potential to replace conventionally used cookie fat [96, 97]. Although some differences in cookie hardness and color have been detected due to fat replacement (Fig. 26.4a1–a3), improvements in FAP and starch digestibility were remarked [96]. Moreover, emulsion-templated approaches were tested as total or partial substitutes for commercial fats or oils [98, 100]. By replacing oil with a low-vanillin content oleogel (without emulsifier), the spread ratio, hardness, and ΔE of cookies were diminished, resembling shortening-cookie properties [100]. Those oleogel structures probably interact with proteins and starch in a more butter-like than oil-like manner, providing techno-functional properties more similar to a commercial fat—although FAP was notably modified, lowering SFA by 20–80% and increasing UFA by 90–370%. Varying some structurant characteristics, such as the fatty acid chain length of polyphenol ester, modified oleogel properties more significantly than those of cookies [98]. In contrast, fat replacement level was strongly reflected in some product properties, generating harder doughs and cookies with higher break strength and lower overall quality scores as butter replacement was increased [98, 99]. Additionally, when HPMC emulsion-based or foam-templated oleogels were used instead of shortening, harder cookies were obtained, resulting in low consumer acceptance [94]. Some product texture properties were raised by increasing the amount of MG in an HPMC-MG oleogel, which corresponded to the formation of more compact structures (Fig. 26.4a4–a6) generated by reduced dough aeration [75]. However, no differences in spread ratio or overall appearance were observed when esterified rice flour with citric acid (ERCA)-BW oleogels were used, although a 28% UFA increase was achieved [93].

Medium chain triglycerides-EC oleogels obtained through high intensity ultrasound (HIU) gelation were introduced in cookie formulation [91]. HIU-based oleogels allowed to obtain cookies with good texture and not as hard as those produced with non-HIU oleogels. Sensory scores and overall acceptability were improved by using HIU-based oleogels.

Crackers and breads, although typically require low fat content (<10%), still need the properties that fats provide [55, 56]. MG and RBW oleogels were shown to

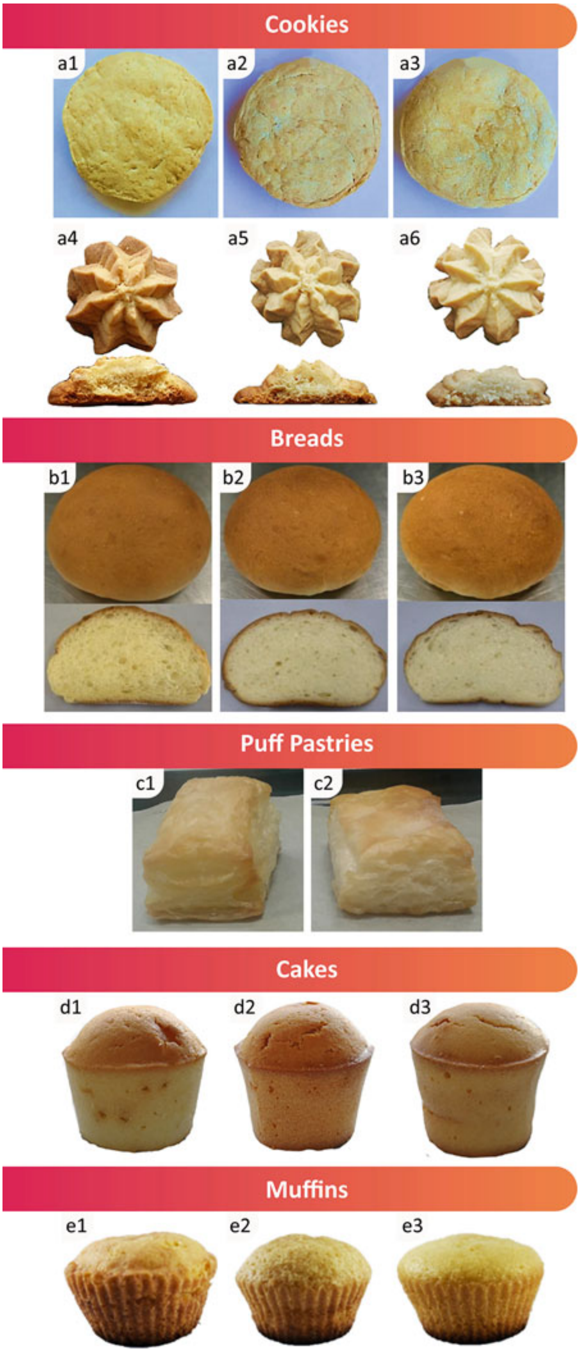

Fig. 26.4 Appearance of bakery products elaborated with different oleogel-based systems compared with a control product: (**a**) cookies from (a1) commercial shortening, candelilla wax oleogel-based bigel with (a2) 50% and (a3) 100% fat replacement, reproduced from [96] with permission from Elsevier, and from 50% fat and 50% hydroxypropyl methylcellulose (HPMC)-saturated monoglycerides (MG) oleogels with (a4) 0 wt% MG, (a5) 4 wt% MG, and (a6) 10 wt% MG, reproduced from [75] with permission from Elsevier; (**b**) breads from (b1) margarine and (b2, b3) oleogels from two different sodium stearyl lactates, reproduced from [56] with permission from Elsevier; (**c**) puff pastries from (c1) commercial laminating margarine and (c2) MG: saturated fatty acid-dried emulsion, reproduced from [106] with permission from John Wiley and Sons; (**d**) cakes from 50% fat and 50% HPMC-MG oleogels with (d1) 0 wt% MG, (d2) 6 wt% MG, and (d3) 8 wt% MG, reproduced from [75] with permission from Elsevier; and (**e**) muffins from (e1) margarine, (e2) unstructured oil, and (e3) optimized MG oleogel, reproduced from [38] with permission from John Wiley and Sons

be acceptable options to replace shortening in these formulations [55]. MG oleogel was postulated as a retardant of starch gelatinization and retrogradation and as a crumb softener, leading to a better performance than RBW oleogel and commercial shortening during bread but not for cracker production. However, lubrication and gluten network development were similar in the three lipid-based systems and, therefore, in the final product appearance. In low-fat bread doughs, water absorption was not modified by the type of fat used [55], although it was in doughs with higher lipid amounts [55, 109]. An EC-triglyceryl monostearate oleogel-based shortening also displayed superior properties to a commercial fat for producing softer breads with higher specific volume [40]. Breads formulated with SSL oleogels achieved a similar general appearance to those formulated with margarine (Fig. 26.4b) or sunflower oil, even with some textural property differences and a 30% reduction in SFA compared to margarine-based breads [56].

Also, it has been shown that oleogelation can greatly affect the final characteristics of sweet bread, in which 12–19% fat is used. Butter replacement with up to 75% CLW oleogel led to obtaining breads with specific volume and hardness similar to the control, even reducing SFA from 71 to 35% [58]. Moreover, palm oil substitution by sunflower oil or by the corresponding MG oleogel was detrimental to bread specific volume, but the use of an MG hydrogel resulted in a product with quality characteristics comparable to those of the control, although both gels implied a reduction of ~80% SFA [59]. This fact evidenced that MG interacted in different ways depending on the phase or interface in which they are found, going from the generation of an inhomogeneous lipid distribution and the corresponding lower leavening effect by the MG oleogel to a better interaction with the preparation ingredients—water, starch, and gluten—by the MG hydrogel.

Baked or steamed buns were also reformulated by substituting margarine with oleogels based on HPMC and XG [57]. Although implying a great FAP improvement, no differences were detected in crumb structure, bun shape, texture, sensory attributes, or lipid digestibility.

Puff pastries are laminated doughs that require high fat content (~37%) to be properly mechanized to reach rheological fat-dough equilibration. Laminating CM was fully replaced by high internal phase O/W emulsion produced with MG-SFA, achieving satisfactory performance during laminating and baking and a good final appearance (Fig. 26.4c)—with ~7% SFA reduction—[106, 107]. Although an increased oiliness in the mouth was detected, product friability was satisfactorily maintained. Other emulsion formulations based on olive pomace oil, PS, and different gelators—BW, saturated triglycerides, or MG—were postulated as possible alternatives for puff pastry fat [110]. Although acceptable approximations were achieved between the BW emulsion and the commercial product, the final product functionality remains to be tested.

Cakes, with a characteristic spongy structure due to air entrapment, are usually made with 10–25% butter or margarine. When conventional cake fats were replaced by some wax oleogels, batters with lower viscosity and less shear-thinning behavior were obtained, which affected batter aeration [63, 64]. Cake porosity and specific volume decreased using wax oleogels instead of shortening, resulting in harder cakes with higher chewiness [64]. Exceptionally, BW oleogel-based cakes maintained a similar specific volume to the control although doubling in hardness [64], while CLW oleogels increased cake specific volume reducing hardness [61]. Crumb structures with homogeneously distributed fine air cells were obtained using shortening and BW oleogels [64]; however, less amorphous areas and more hydrated and short-range crystallized starch networks were reported using CLW oleogels [61]. Nevertheless, a consumer health problem could be introduced due to the proposed substitution, since the in vitro starch digestibility increased with it. Although total substitution can reduce cake SFA by ~70%, partial replacement might be a better option for maintaining cake properties. Oils structured with CRW—as oleogel or emulsion—were also used to partially replace a high-fat material in cakes [70]. In general, UFA increment did not affect batter's rheological behavior nor cake's textural and sensory properties. Gelled emulsions produced batters with higher consistency and cakes with greater aeration than oleogel-based cakes; however, the latter had the highest overall acceptability by consumers. Full margarine replacement with SLW oleogel-based emulsions also showed that, while the batter exhibited unfavorable properties compared to the control, the cake had acceptable texture and sensory characteristics [48].

Oleofoams from wax oleogels were used to replace palm fat in cakes [60]. Although some waxes such as SFW showed a good ability to generate oleogels, this was not transferred to the behavior of oleofoams nor to those of oleogel-based batters. The different behaviors were related to the varying arrangement of wax crystals in air interphase or bulk oil. However, only minor differences were found in cakes, being BW oleogel the preferred to diminish oil migration. Moreover, although sensory results did not show that cakes were much different, oleogel-based cakes got higher scores.

A gluten-free batter for producing aerated products was reformulated using BW oleogel co-crystallized with a commercial cake shortening [62]. Full replacement produced batters with reduced air-holding ability and cakes with lower porosity and specific volume. However, similar properties to control cakes were obtained with partial replacement.

Oleogels from MG and BW were also used as margarine replacers [65] and as a result of a higher moisture retention capacity, reformulated cakes with higher porosity and dimensional values than the control were obtained. After sensory analyses, an MG-BW-HOSO-based cake was preferred even over control. Moreover, the shelf life of this reformulated cake was extended, diminishing its oil migration. Binary systems from different gelators reinforced with adipic acid (AA) have been used to improve cake properties. Acceptable texture profile, color, and organoleptic properties were obtained by 50% shortening substitution with CRW-AA or EC-AA oleogels, making these results better than those obtained without the reinforcement [66, 67]. Moreover, the partial substitution with EC-AA oleogel resulted in cakes with greater oxidative stability [68]. Some acceptable results were obtained when using oleogels from PS or sucrose stearate/ascorbyl palmitate blends to replace shortening in a low-fat cake recipe, improving cake oxidative stability compared with oil-based cake but not reaching that of shortening one [69].

Polymer-stabilized O/W emulsion-based oleogels have been used to replace commercial fats or oils. Full replacement of margarine, peanut oil, or shortening resulted in softer and spongier cakes with higher adhesiveness [71, 72]. Moreover, the non-uniform pore distribution in oil-based cakes could be partially overcome by using oleogels [72]. Although cake texture was nearly maintained when shortening was partially or even totally substituted with a gum emulsion-based oleogel, sensory analysis showed that the 75% replacement-based cake was preferred over the control [73]. Along with the search for improvements in emulsion stability and shelf life, e.g., by using antioxidant compounds, reformulation effects on final product properties must be considered. By using an optimized emulsion-based oleogel including polyphenols, oil oxidation was retarded and batter and cake properties more similar to margarine-based than oil-based products were obtained [74].

Foam template-based oleogels were used to partially replace commercial butter in a low-gluten cake, achieving improved hardness and chewiness but showing no major effect on the final product appearance (Fig. 26.4d) [75]. Increasing MG content resulted in higher dough density and lower cohesiveness and resilience cakes. Moreover, cakes prepared using protein foam-based oleogels were harder than shortening-based cakes, although similar to oil-based ones, probably because oil and protein oleogel could not avoid the starch-protein adhesion and thus product staling [76]. Adding another structurant may help to overcome this issue. In addition, the cake color was modified by oleogel ingredients, although they were at low concentrations ensuring maintenance of healthy oil composition.

Muffins or cupcakes are a special baked cake type. An optimized MG oleogel proved to be an effective replacement for CM, not only from measured properties but also due to sensory analysis and consumer acceptance (Fig. 26.4e)—with 68 and 100% SFA and TFA reduction, respectively—[38, 101]. By increasing the shortening replacement level with HPMC foaming-templated or CLW oleogels, batter specific gravity tended to increase and muffin air cells were bigger, closer, and not evenly distributed [102, 104, 105]. However, muffin specific volume was not modified with up to 50 or 25% replacement depending on the used system, ensuring an improvement in the UFA:SFA ratio of at least 42%. In addition, when shortening was replaced with MG-enriched CLW oleogels, muffins with similar porosity and improved textural characteristics with respect to CLW oleogels were produced [102]. The addition of β-carotene in CLW-MG oleogels did not adversely affect muffin structural characteristics; however, muffin color changed, and its oxidative stability was improved.

By replacing shortening with different wax oleogels in a gluten-free muffin recipe, water content, physical parameters, and textural properties were not significantly affected, although dough specific gravity was slightly increased and muffin porosity modified [103]. Muffin crust color changed depending on the wax used ($\Delta E < 6$) and lipid fraction was modified, diminishing ~40% SFA and increasing ~45% UFA.

Tart pastries need solid fats to form properly. Oleogels from EC, MG, or EC-MG were used to replace butter and palm shortening [108]. MG oleogels and control fats produced doughs with similar firmness. However, MG oleogel-based tart had lower hardness than the control. On the other hand, EC oleogel-based dough and tart were the firmest and most hard. However, combining EC and MG was a successful strategy to improve textural properties and dough workability.

26.4 Confectioneries

The quality of chocolate, fillings, and related confectioneries is significantly affected by the fat phase. Therefore, its substitution is the main challenge facing the confectionery market due to changes in thermal properties and oil migration that occur during storage. In this regard, different oleogel-based systems have been proposed as fat replacers (Table 26.3), offering promising results.

Cocoa butter constitutes a main ingredient in confectionery due to its fat or triglyceride composition—high in SFA—resulting in unique physical and sensory characteristics of final products. CB equivalents are needed, not only because of excessive fat consumption but also because it is the most expensive confectionery ingredient. Against this background, HPMC structured HOSO to develop an emulsion-templated oleogel with a healthier FAP to be used as a partial or complete CB substitute [111]. Oleogel incorporation resulted in a significant effect on hardness, which decreased as oleogel quantity increased in the system, probably due to the difference in SFC, i.e., SFA contributed more solidity. Although OBC was also affected by the substitution, very high values were still obtained (>93%), showing that strong networks had been formed. Among the reformulated systems, similar rheological and textural characteristics to CB were obtained with 50% replacement.

Chocolate is globally consumed primarily for its sensory stimulation and excitement potential. However, because it is composed mainly of CB or milk fat—both responsible for hardness, temperability, and melting point—it is a high-calorie product containing up to 40% SFA [126]. Consequently, fat replacers for healthier chocolate formulations that maintain the desirable physicochemical and sensorial properties are required. Recently, MG-palm oil oleogels combined with some healthy sweeteners—maltitol, tagatose, and palm sugar—were tested as CB replacers to prepare heat-stable and bloom-resistant chocolate [113]. As a result of the reduced CB content, all reformulated products were significantly less hard. The 50:50 sucrose:palm sugar oleogel-based chocolate presented the polymorphic structure required in this type of product (β crystals) to provide stable crystal networks. In turn, it improved the shape-retention capability, maintained high bloom resistance, and displayed higher melting enthalpy compared to the pure CB chocolate. Moreover, this reformulated chocolate showed the highest overall acceptability, with no waxiness by fast mouth fusion. Three oleogels structured by MG, EC, or BS-LC were used to reformulate dark chocolate with total or partial substitution of CB [114, 115]. Incorporating oleogels resulted in chocolates with soft texture, shear-

Table 26.3 Oleogel applications in confectionery products

Food product	System	Gelator (wt% in system)/oil	Replaced fat (wt % replacement)	Reference
Cocoa butter	Emulsion-templated oleogel	HPMC (1)/HOSO	CB (50, 60, 70, 80, 100)	[111]
	Oleofoam	CB (15, 22, 30)/HOSO	CB (70, 78, 85)	[112]
Chocolate	Oleogel	MG (10)/palm	CB (30)	[113]
	Oleogel	MG, EC (10), BS:LC (8:2)/corn	CB (50)	[114]
	Oleogel	MG, EC (10), BS:LC (8:2)/corn	CB (50, 100)	[115]
	Oleogel	BS: Stearic acid (2.4:9.6), BS:GO (4.8:7.2), BS:LC (9.6:2.4)/corn	CB (50)	[116]
	Foam-templated oleogel	HPMC (2)/sunflower	CB (30, 50, 70, 100)	[117]
	Emulsion-templated oleogel	HPMC (0.5–2)/HOSO	CB (50)	[118]
Filling creams	Oleogel	MG (10)/HOSO	Beef fat (100)	[119]
	Oleogel	BW (1.5–3.5)/rice bran	Palm oil (17, 33, 50)	[120]
	Oleogel	CRW (6)/pumpkin seed	CB (100)	[121]
	Oleogel	MG (3, 6), STS:LC (3:3, 4:4, 5:5)/soybean	Filling fat/coating fat (100)	[122]
	Oleogel	MG:CLW (10:0, 4:6, 0:10)/canola	Shortening (100)	[123]
	Oleogel	MG:CLW:HF (0.35–1.40:0.35–1.05:0.35–1.75)/soybean, HOSO	Shortening (100)	[124]
	Oleogel	BS:GO (5:5, 12.5:12.5)/sunflower	*n.a*	[125]

BS β-sitosterol, *BW* beeswax, *CB* cocoa butter, *CLW* candelilla wax, *CRW* carnauba wax, *EC* ethylcellulose, *GO* γ-oryzanol, *HF* hard fat, *HOSO* high oleic sunflower oil, *HPMC* hydroxypropyl methylcellulose, *LC* lecithin, *MG* saturated monoglycerides, *n.a* not applicable, *STS* sorbitan tristearate

thinning behavior, and a high degree of unsaturation [115]. The polymorphic form and thermal properties were similar to the traditional chocolate. However, the different gelation mechanisms of the three kinds of oleogels resulted in variations in some physicochemical properties of reformulated products. For 50% replacement, EC oleogel-based chocolate had the highest hardness, which was attributed to higher SFC and particle-particle interactions. Nevertheless, MG oleogel was the only one that could form a solid-like chocolate with total CB replacement. Furthermore, these oleogels improved chocolate bloom stability during different storage conditions, even with reduced saturation levels [114]. While an incipient bloom was detected at 1 day of cold storage (Fig. 26.5a1–a4), this was reversed with longer storage time obtaining non-significant differences between samples. Furthermore, under fluctuating temperatures, oleogel-based chocolates exhibited bloom-delaying properties.

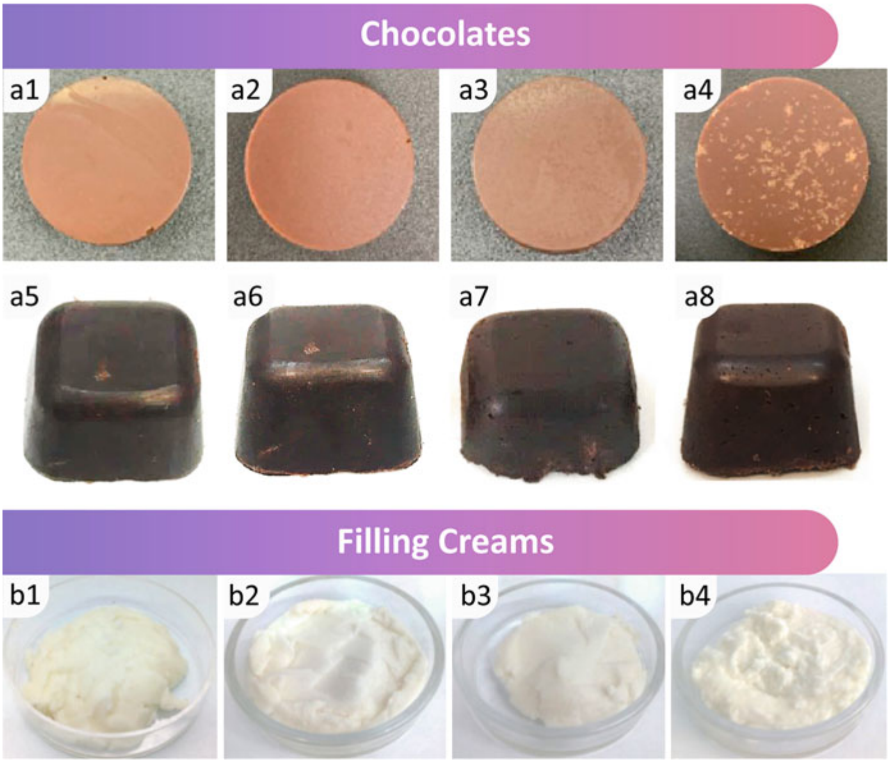

Fig. 26.5 Appearance of confectioneries elaborated with different oleogel-based systems compared with a control product: (**a**) chocolates from (a1) cocoa butter, (a2) MG oleogels, (a3) BS-LC oleogels, and (a4) EC oleogels, all stored at 4 °C for 1 day, reproduced from [114] with permission from Elsevier, and from (a5) cocoa butter and hydroxypropyl methylcellulose (HPMC) oleogel with (a6) 0.5 wt% HPMC, (a7) 1.5 wt% HPMC, and (a8) 2 wt% HPMC, reproduced from [118] with permission from Elsevier, under the terms of the Creative Commons CC-BY 4.0 license; and (**b**) filling creams from (b1) commercial fat and variable amounts of saturated monoglyceride oleogel (b2) 26%, (b3) 30%, and (b4) 40%, reproduced from [119] with permission from John Wiley & Sons

Due to fat bloom formation, dark chocolate showed bigger hardness changes during storage than oleogel-based chocolates, which remained thermally and polymorphically stable. Similarly, other binary oleogels from BS combined with γ-oryzanol (GO), stearic acid, or LC were investigated to replace CB in dark chocolate [116]. Although some properties differed between the three oleogels, reformulated chocolates exhibited the required β crystals, as well as similar characteristics as that of dark chocolate.

In addition to oleogels, other replacement systems based on HPMC were addressed to reformulate chocolates. For instance, a foam-templated approach was tested as a partial or total CB substitute [117]. Despite some differences in properties between oleogel-CB blends, these differences diminished when other ingredients were added to oleogel-based chocolate formulations. All reformulated products presented an improved FAP, proportionately to CB replacement. Nonetheless, a sensory analysis indicated that HPMC oleogel could replace CB up to 70%, although a technological perspective would suggest a replacement level of 50%. Other HPMC oleogels obtained by emulsion-templated approach were developed to produce a healthier chocolate with lower fat content and optimum sensory properties [118]. Oleogel-based chocolates had a similar appearance to CB-based ones (Fig. 26.5a5–a8), but softer texture related to the structurant amount in the oleogel. Furthermore, texture and flavor were negatively impacted by the highest HPMC concentration, while more similar sensory properties to those of the control were achieved with the lowest proportions of cellulose. To summarize, the majority of research has concentrated primarily on dark and milk chocolate reformulations, while those for white, compound, and ruby chocolate should also be examined to determine how low-calorie ingredients affect their properties.

Filling creams represent an important ingredient in different food products, such as cookies and filled chocolates. Based on their composition—large amounts of fat and sugar—they are considered unhealthy products and their consumption is concerning. As a result, it is becoming increasingly important to replace or reduce the use of HF in these formulations maintaining the required physical and organoleptic properties. In light of this, an MG oleogel was tested as a fat material in filling creams for sandwich cookies [119]. Creams prepared with variable oleogel amounts resulted in a significant impact on final properties and appearance (Fig. 26.5b). Increasing oleogel concentration, softer creams with higher adhesiveness than the control were obtained, improving cookie adhesion. Wax oleogels have also been proposed to replace filling cream fats. Up to 17% replacement was possible with BW oleogels, maintaining high OBC and significantly lowering SFA content [120]. Incorporating lucuma powder into a CRW oleogel resulted in creams with lower saccharose levels without affecting OBC and water activity, ensuring physical and microbiological stability [121]. In a model praline system, MG oleogels displayed better migration-delaying properties than STC-LC oleogels [122]. Additionally, these oleogels were fully melted at body temperature, not causing waxiness. Moreover, multicomponent oleogels have been used in filling production aiming to obtain a healthier product [123, 124]. For instance, a reduction of at least 53% in SFA and 100% in TFA was achieved with some MG-CLW-HF oleogels, as well as good technological properties [124].

26.5 Meat-Based Products

Meat product final quality is greatly affected by the amount and/or composition of the animal fat employed, as it contributes to textural characteristics—tenderness, palatability, juiciness—as well as flavor and physical appearance. Nonetheless, excessive consumption may be harmful to human health due to its high SFA, TFA, and cholesterol content [127, 128]. Hence, proper strategies are needed to produce reformulated low-fat meat products with healthier FAP maintaining consumer acceptance. This section assesses the development of a range of meat products whose natural fat profile has been modified with different oleogel-based systems, as shown in Table 26.4.

Burgers are the most popular fast food across genders and cultures, containing between 20 and 25% animal fat. Different oleogels have been proposed as fat replacers for burger formulations, achieving improved FAP. Oxidative stability and hardness of BW oleogel-based patties were lower compared to the control [130, 131], while using EC oleogels enhanced textural properties, although it also reduced oxidative stability [129]. Moreover, sensory analysis revealed high ratings for BW oleogel-based burgers, opposite to EC-SMS ones, which scored below neutral [131]. Patties with some acceptable characteristics were obtained using EC and CRW oleogels reinforced with AA, even significantly better than those formulated with non-reinforced oleogels [66, 67]. Additionally, GO-BS-linseed oil oleogels did not alter burger texture while improving its nutritional profile [132]. Overall, lower fat replacement products were accepted by consumers, despite a marked preference for the control.

Reformulated hamburgers with foam-based oleogels were softer, having an enriched FAP due to a $\sim$ 65% SFA reduction [134]. Recently, bigels using EC oleogels have shown great potential in a meat product [135]. Compared to the control, bigel-based burgers showed improved cooking properties and sensory analysis scores. However, lipid oxidation increased with bigel incorporation, which could be improved by adding antioxidants or other structurants.

Meatballs consist of ground meat rolled into a ball with other ingredients. A healthier meatball was designed based on the partial replacement of beef fat with CRW oleogels, negatively affecting their textural properties [139]. Oxidative stability was affected not only by the amount of fat substitution but also by the type of oil used in the oleogel, improving by raising the MUFA:PUFA ratio. Meatballs with 25% sunflower oil oleogel substitution scored significantly higher than the control in some characteristics and overall acceptability.

Meat batters are made of water, fat, and protein, and thus they are considered emulsions. Consequently, fat and moisture stabilization is essential to the manufacture of these products. Total fat substitution in meat batters has been studied by different replacement systems. Healthier FAP was achieved with structured canola oil systems—kappa-carrageenan emulsions or EC oleogels—by decreasing SFA and the n-6/n-3 ratio and increasing PUFA [140]. Reformulated products showed similar color and texture to the control while reducing lipid oxidation. Additionally, oleogel-based batters showed better matrix stability than emulsion-based ones, with a more uniform microstructure and no fat losses. Multicomponent oleogels from soybean oil also decreased lipid oxidation, but no effects on texture were observed [141]. Although reformulated batters were darker and less red, products were accepted. Moreover, cellulose-based oleogels significantly increased PUFA while keeping total fat content close to control levels.

Table 26.4 Oleogel applications in meat-based products

Food product	System	Gelator (wt% in system)/oil	Replaced fat (wt% replacement)	Reference
Burgers	Oleogel	EC (10)/sesame	Animal fat (25, 50)	[129]
	Oleogel	BW (10)/rapeseed	Beef fat (100)	[130]
	Oleogel	BW (11), EC:SMS (11:3.67)/olive:linseed:fish (44.39:37.87:17.4)	Pork backfat (100)	[131]
	Oleogel	EC:AA (2:4)/soybean	Flank and shank fat (50)	[67]
	Oleogel	CRW:AA (2:4)/soybean	Bovine fat (50)	[66]
	Oleogel	GO:BS (4.8:3.2)/linseed	Pork backfat (25, 75)	[132]
	Oleogel	GO:BS (n.s)/linseed	*n.a*	[133]
	Foam-structured oleogel	HPMC (4)/canola	Beef tallow (50, 100)	[134]
	Bigel	EC (10)/sunflower	Animal fat (25, 50, 75)	[135]
	O/W emulsion	Pork skin (20)/olive	Bovine backfat (100)	[136]
	O/W emulsion	Prosella® (6.7)/olive	Pork fat (100)	[137]
	O/W emulsion	Sodium alginate: Carrageenan: Glycerol monostearate (1:1:1)/olive	Beef backfat (33.3, 66.6, 100)	[138]
Meatballs	Oleogel	CRW (7.5)/sunflower, sunflower: black cumin seed (90:10, 80:20)	Beef fat (25, 50, 75)	[139]
Meat batters	Oleogel	EC (12), EC:MG (12:1.5, 12:3)/canola	Beef fat (100)	[140]
	Oleogel	EC:Avicel RC-591:α-cellulose (7.37:1.815:1.815)/soybean	Pork backfat (100)	[141]
	O/W emulsion	Kappa-carrageenan (1.5, 3)/canola	Beef fat (100)	[140]
Meat sauces	Oleogel	MG (0.5, 2.5), LC (2.5)/olive: sunflower (80:20)	Olive: Sunflower (100)	[142]
	Oleogel	MG, fatty alcohols (0.5, 2.5)/olive:sunflower (80:20)	Olive: Sunflower (100)	[143]
Pâté	Oleogel	BW (8)/linseed	Pork backfat (30, 60)	[144]
	Oleogel	BW (9.12)/linseed	Pork backfat (60, 100)	[145]
	Oleogel	BW (11)/olive:linseed:fish (44.39:37.87:17.4)	Pork backfat (60, 100)	[146]
	Oleogel	EC (14), EC:MG (12–14:1.5–3)/canola	Pork fat (100)	[147]
	Oleogel	EC:MG (12:3)/canola	Lard (20, 40, 60, 80, 100)	[148]

(continued)

Table 26.4 (continued)

Food product	System	Gelator (wt% in system)/oil	Replaced fat (wt% replacement)	Reference
	Oleogel	EC:SMS (11:3.67)/olive:linseed: fish (44.39:37.87:17.4)	Pork backfat (60, 100)	[146]
Salami	Oleogel	EC:MG, EC:SOSA (6–14: 3), EC:LC (8–12:1)/canola	Pork and beef fat (50)	[149]
Sausages				
Bologna	Oleogel	MG (5)/sunflower, HOSO	Pork backfat (25, 50, 75, 100)	[150]
	Oleogel	RBW (2.5, 10)/soybean, high oleic soybean	Pork backfat (100)	[151]
	O/W emulsion	Pork skin (37.5)/HOSO	Pork backfat (25, 50, 75, 100)	[152]
Breakfast	Oleogel	EC (8–14), EC:SMS (8–14:1.5–3)/canola	Pork backfat (100)	[153]
Fermented	Oleogel	MG (15)/olive	Pork backfat (50)	[154]
	Oleogel	BW (10)/olive:chia (80:20)	Pork fat (80)	[155]
	Oleogel	BW (8), GO:BS (4.8:3.2)/linseed	Pork backfat (20, 40)	[156]
	O/W emulsion	Soy protein isolate: Gelatin (10: 3)/olive:chia (80:20)	Pork fat (80)	[155]
	O/W emulsion	Kappa-carrageenan: Polysorbate 80 (1.5:0.12)/linseed	*n.a*	[157]
Frankfurter	Oleogel	BW (8)/linseed	Pork backfat (25, 50)	[158]
	Oleogel	RBW (2.5, 10)/soybean	Pork backfat (100)	[159]
	Oleogel	EC (10)/canola	Beef fat (100)	[160]
	Oleogel	MG:PS (15:5)/sunflower	Pork backfat (50)	[161]
	Oleogel	EC (8, 10, 12, 14), EC:SMS (8–14:1.5–3)/canola	Beef fat (100)	[162]
	Oleogel	EC:SMS (8:1.5, 8:3, 10:1.5)/ canola	Beef fat (20, 40, 60, 80)	[163]
	Oleogel, O/W emulsion	GO:PS (3:7, 6:4, 6:14, 12:8)/ sunflower	Pork backfat (50)	[164]
Sucuk	Oleogel	SFW, BW (10)/flaxseed	Beef tallow fat (100)	[165]
Thai sweet	Oleogel	RBW (2)/rice bran	Pork backfat (25, 50, 75)	[166]
Venison	W/O emulsion	Soy protein concentrate (0.1)/ olive	High-fat pork meat (15, 25, 35, 45, 55)	[167]

AA adipic acid, *BS* β-sitosterol, *BW* beeswax, *CRW* carnauba wax, *EC* ethylcellulose, *GO* γ-oryzanol, *HOSO* high oleic sunflower oil, *HPMC* hydroxypropyl methylcellulose, *MG* saturated monoglycerides, *n.a* not applicable, *n.s* not specified, *PS* phytosterols, *RBW* rice bran wax, *SFW* sunflower wax, *LC* lecithin, *SMS* sorbitan monostearate, *SOSA* stearyl alcohol/stearic acid

Meat sauce stabilization is a relevant issue due to the difficulty of structuring oil phases. Oleogelation can improve system quality and organoleptic properties as gelators structure the oil phase into a semi-solid gel network linking solid particles, thus preventing or delaying separation [14]. Taking this into account, MG and LC oleogels were tested as replacers for liquid oil in meat suspensions [142]. Both exert a stabilizing action on the sauces, although MG oleogels reduced phase separation more effectively than LC. Even with the lowest MG concentration, a stabilized sauce with similar rheological properties to those of the control was obtained. Likewise, MG or fatty alcohol oleogels were used in meat suspensions to improve their stabilities—being fatty alcohols more efficient than MG, even at low concentrations—[143]. Moreover, both oleogels enhanced meat sauce mechanical stress resistance without altering their consistency.

Pâté is a highly appreciated spreadable meat product known for its flavor and smooth texture, containing 17–50% animal fat [128]. BW oleogels were tested to replace pork backfat in liver pâtés, obtaining products with optimal FAP. Pâté stability, sensory parameters, and texture were not significantly affected by substitution with an olive, linseed, and fish oil oleogel [146]. Conversely, when a linseed oil oleogel was used, a decrease in hardness and adhesiveness was observed [144]. Fat replacement significantly increased lipid oxidation [146], which could be compensated by antioxidant incorporation [145]. Other reformulated pâtés made from EC or EC-MG oleogels exhibited higher oil loss than the control, possibly due to the formation of larger fat globules [147]. Also, they all had similar sensory hardness, oiliness, juiciness, and cohesiveness as the control. Overall, the 12:3 EC: MG oleogel-based pâté demonstrated the best performance in achieving similar characteristics to the control, while also successfully reducing SFA. By substituting up to 60% pork fat with this binary system, the final product demonstrated good oil retention and improved textural properties, without modifying sensory properties and color [148]. An EC-SMS oleogel prepared using a lipid mixture of olive, linseed, and fish oils was also tested, yielding products not significantly different from the control in technological behavior and physicochemical properties, except lipid oxidation [146]. Additionally, although all samples were rated near neutral, sensory parameters showed a negative effect.

Salami, a coarse ground meat product, has large fat particles that play a crucial role in their appearance, texture, and mouthfeel; hence, its replacement without product destabilizing is a challenge. Fat partial replacement with different canola oil oleogels—from EC-MG, EC-LC, or EC-stearyl alcohol/stearic acid—was proposed [149]. Structuring canola oil led to a microstructure with fat globules similar to the control. Specifically, EC-LC oleogels produced larger gelled oil particles that effectively bind to the protein matrix. Texture parameters were not affected in most formulations.

Sausages consist of ground meat and non-meat ingredients which contribute to the quality, taste, and aroma of the final product. Several types of sausage are available, including fresh, smoked, cured, and cooked [128]. *Bologna sausages* have been reformulated with oleogel-based systems from different gelators. MG oleogels were used to replace pork fat, resulting in sausages that were easier to slice than the control, possibly due to a more compact product structure as the amount of pork fat was reduced [150]. Despite some modified textural properties, most replacements produced stable emulsions that were sensorially accepted by consumers with increments in UFA. Oleogels formulated with soybean or high oleic soybean oil and RBW were also tested to totally replace pork backfat [151]. Sausage quality and organoleptic properties were not affected by the oil type, except for FAP, which was improved by the high oleic type resulting in products with lower n-6/n-3 ratios. In addition, no sensory differences were detected in terms of aroma, flavor, texture, and moistness, but the color of the control was more intense. Oleogel-based bologna sausages had fewer and larger lipid globules than unstructured oil-based ones, more closely resembling pork fat sausages. Stable batters were obtained with the use of oleogels instead of control fat, observing water separation for the sausages containing oil without structurant [150, 151].

Breakfast sausages were reformulated using oleogels from canola oil structured with EC or EC-SMS to totally replace pork backfat [153]. SMS incorporation improved hardness values being similar to those of control. However, sensory hardness could not be matched by oleogels, and therefore samples were generally less sensory juiciness and oiliness, while the replacement with ungelled canola oil had comparable values to the control.

Fermented sausages have been produced with different oleogel-based systems to evaluate the effects of pork backfat replacement. An MG-olive oil oleogel showed promising results by replacing 50% fat [154]. Reformulated sausages were sensory acceptable and microbiologically safe, with an enhanced FAP by reducing ~19% cholesterol and ~17% SFA and increasing ~9% MUFA. Similarly, two oleogels from BW or GO-BS and linseed oil were tested as replacers [156]. Gelator type and replacement level led to significant differences in various physicochemical and mechanical properties as well as consumer acceptability—probably due to modifications generated in the drying process from different initial water contents. Sausage nutritional profile was improved with oleogel incorporation achieving the greatest reductions in SFA with the highest level of replacement. However, oleogel-based sausages revealed lower sensory acceptance than the control.

Not only oleogels but also emulsions were tested to replace the fat in this type of sausages. The ability of wax oleogels and emulsion gels formulated with a mixture of olive and chia oils to replace fat was studied [155]. Both replacement strategies enriched FAP with decreased SFA and increased PUFA. Sausage oxidative stability and their microbiological and technological properties were not affected using oleogel or emulsion, except for hardness (oleogel $<$ emulsion $\sim$ control). Reformulated sausage sensory attributes scored similarly, but lower than control. Besides, the lipid source affected the cross-sectional appearance, perfectly distinguishing the animal fat in the meat matrix of the control product, whereas the presence of oleogel or emulsion in the reformulated products was less discernible (Fig. 26.6a). To preserve product quality, a linseed oil emulsion added with a natural antioxidant extract was used [157]. The extract could enhance sausage physicochemical properties and prolong their shelf life, even using a high-PUFA oil.

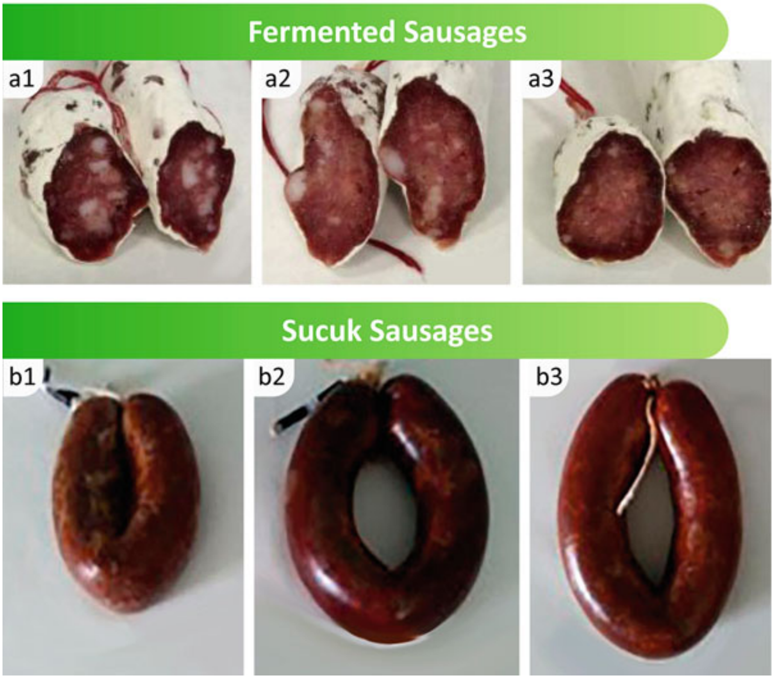

Fig. 26.6 Appearance of meat-based products formulated with different oleogel-based systems compared with a control product: (**a**) low-fat fermented sausages from (a1) animal fat and with 80% fat replacement using wax (a2) oleogel and (a3) emulsion, reproduced with permission from [155] under the terms of an open access Creative Commons CC BY 4.0 license; and (**b**) sucuk sausages from (b1) animal fat, (b2) beeswax oleogel, and (b3) sunflower wax oleogel, reproduced from [165] with permission from Elsevier

Frankfurter sausages have also been successfully manufactured with a variety of oleogel-based systems. For instance, BW-linseed oil oleogels were tested to replace backfat significantly improving sausage FAP by reducing SFA and cholesterol content and balancing the n-6/n-3 ratio [158]. Although some physicochemical, mechanical, and sensory properties were unfavorable, all reformulations scored positively and received acceptance; however, the control received the highest acceptability. Fat total replacement was evaluated using RBW-soybean oil oleogels, significantly reducing frankfurter flavor [159]. Gelator concentration affected product quality, but not enough to distinguish their texture from that of the control. Another monocomponent oleogel—EC-canola oil—was investigated to totally replace fat, resulting in products with improved texture compared to those made with ungelled oil and similar chewiness and hardness to the control [160].

Fat partial replacement was also studied using binary oleogels from PS and a high MG content, resulting in sausages with a PUFA-rich and SFA-low lipid profile [161]. Although some differences in texture were found between oleogel-based frankfurters and the control, sensory analysis indicated that reformulated products were generally accepted. Furthermore, frankfurter reformulation substituting 100% beef fat with EC or EC-SMS oleogels showed the possibility of tailoring textural and sensory sausage properties [162]. Without SMS addition, lower sensory hardness than that for ungelled oil was obtained. When an 8:1.5 or 8:3 EC:SMS ratio was used, hardness was similar to the fat control, while higher EC concentrations resulted in a significant increase in this parameter. Likewise, the same binary system was used to reformulate frankfurters based on the partial replacement of beef fat [163]. Sausage containing 10:1.5 EC:SMS oleogel had the most similar parameters to the control. In addition, juiciness and oiliness increased as replacement levels increased, while smokehouse and water losses decreased. The use of GO-PS-sunflower oil oleogels or their emulsions was also assessed to partially replace pork backfat [164]. Compared to the control, oleogels did not affect any sausage textural parameters, while emulsions reduced chewiness, hardness, and gumminess. Furthermore, all treatments had similar acceptance, except for some emulsion-based sausages.

Sucuk sausages were reformulated with flaxseed oil oleogels from BW or SFW to replace 100% fat [165]. Some color variations were observed, which could be due to differences in fat sources used (Fig. 26.6b). Oleogel-based sausages had lower textural and sensory properties and consumer acceptance than the control, but an ~ 17% increase in PUFA and essential fatty acids.

Thai sweet sausage formulation was redesigned with a RBW-rice bran oil oleogel to replace the traditional fat, resulting in a product with improved FAP and some changed final characteristics [166]. For 75% replacement, softer sausages with the lowest cholesterol level were obtained, while the highest overall acceptance was reached with 50% replacement.

Venison sausages were reformulated by replacing high-fat pork meat with an emulsion from olive oil and soy protein [167]. During ripening, all replacements showed satisfactory physicochemical characteristics and acceptable levels of lipolysis and lipid oxidation. Although all emulsion-based sausages were accepted by consumers, those containing no more than 25% emulsion were preferred.

26.6 Dairy Products

Different reformulations studied to decrease SFA in dairy-based products—and/or to simulate them as vegan products—are presented in Table 26.5.

Cheese, being recognized as a great protein source, is usually formulated with a high content of saturated fats, whether of dairy or vegetable origin [168]. Both fat content and composition affect important cheese properties such as flavor, rheology, texture, and appearance [170]. Therefore, the replacement of high SFA feedstock with oleogel-based systems can drastically impact product quality and consumer acceptance. CRW oleogels were tested as palm oil full replacers in the production of a low SFA cheese mimic, obtaining an increase in product elasticity, hardness, and chewiness and at least 85% SFA reduction [168]. In addition, oleogel color was transferred to the final product, generating slightly darker structures.

Cream cheese is a fresh, fermented, unripened spreadable product with a high moisture and HF (~30%) content and a whitish base color. RBW or EC oleogel-based cream cheesees were successfully structured showing microstructures with similar fat globule size to a full-fat commercial sample and, consequently, were similar in hardness, spreadability, and stickiness [170]. Also, a 25% reduction in total fat and a 120% increase in UFA were achieved. RBW was preferred to EC as the structurant of high oleic soybean oil instead of the regular type. Although no or little differences were detected between texture and mouthfeel of an RBW oleogel-based cream cheese and a control, flavor intensity and bitterness were rated as stronger, warranting some additional reformulation corrections. Additionally, the whole reformulation process had a protective effect against oxidation [169].

A cheese product based on commercial fat partial replacement with RBW or SFW oleogel was proposed [171]. Structural differences in the shapes of fat globules and their connections were associated with possible differences in protein interactions with SFA and UFA. However, increasing wax content favored a better oil

Table 26.5 Oleogel applications in dairy-based products

Food product	System	Gelator (wt% in system)/oil	Replaced fat (wt% replacement)	Reference
Cheese	Oleogel	CRW (3, 6, 9)/canola	Palm oil (100)	[168]
Cream cheese	Oleogel	RBW (10)/high oleic soybean	Commercial cream cheese fat (100)	[169]
	Oleogel	RBW, EC (10)/high oleic soybean, soybean	Commercial cream cheese fat (100)	[170]
Processed cheese	Oleogel	RBW, SFW (5, 10)/soybean	Commercial cheese fat (41.8)	[171]
Ice cream	Oleogel	RBW (10)/HOSO	Milk fat (100)	[172]
	Oleogel	RBW, CLW, CRW (5, 7, 10)/HOSO	Milk fat (100)	[173]
	Oleogel	EC:UMG, EC:MG-DG (10:3)/HOSO	Coconut fat (100)	[174]
	W/O emulsion	Hydrolyzed collagen:PS (5:23.75)/n.s	Milk fat cream (50, 100)	[175]
	O/W emulsion	Whey protein (46.03)/LC-added high oleic palm oil	Milk fat cream (100)	[176]
	O/W emulsion	PS:GO (0.128–0.384:0.192–0.576)/sunflower	Milk cream (100)	[177]
Vegan cream	Oleogel	CLW (3)/rapeseed:linseed (1:1)	Milk fat, palm oil (100)	[178]
	Emulsion-templated oleogel	Basil seed gum:Soy protein (1:0, 2:1)/n.s	Fat (100)	[179]

CLW candelilla wax, *CRW* carnauba wax, *DG* diglycerides, *EC* ethylcellulose, *GO* γ-oryzanol, *HOSO* high oleic sunflower oil, *LC* lecithin, *MG* saturated monoglycerides, *n.s* not specified, *PS* phytosterols, *RBW* rice bran wax, *SFW* sunflower wax, *UMG* unsaturated monoglycerides structuration, reaching rheological and texture properties similar to control. Moreover, although reformulated products had similar total fat content, an $\sim$ 30% SFA reduction was obtained.

Ice cream is a frozen colloidal structure composed of air bubbles, fat globules, ice crystals, and an unfrozen whey phase, as well as sugar compounds [175]. A semi-solidified emulsion is required to achieve the fat coalescence necessary in the whipping and freezing processes, which leads to air bubble stabilization and, subsequently, to the appropriate overrun and melt resistance. Ice-cream fat—being 6–16% of product—is usually high in SFA, which is recognized as responsible for contributing to the freezing and melting behavior expected in ice cream [180]. In addition, high SFA content provides a smooth ice-cream texture and serves as an aroma carrier [172, 173, 175]. Therefore, the challenge is to maintain the ice-cream structure by replacing HF with vegetable oils, allowing the formation of a suitable colloidal oil network and inhibiting droplet coalescence. Oleogels from HOSO and EC or waxes, added with UMG or MG-DG, were tested as solid fat replacers. To avoid oil overheating during EC system emulsification, a pre-made oleogel method was successfully applied [174]. Although UMG favored the slow melting of wax oleogel-based ice creams due to their fat globule aggregation capability [172, 173], they destabilized EC oleogel-based emulsified structure [174]. However, small and stable globule sizes were obtained using MG-DG in the EC oleogel emulsification [174]. Although oil drop coalescence decreased with EC inclusion, the overrun could not be improved to reach the expected control value. On the other hand, the use of RBW instead of CLW or CRW improved some properties of oleogel-based ice creams, probably due to differences in wax crystallization in oil droplets [173]. Thus, RBW oleogels could favor ice-cream reformulations with 10 and 15% fat.

A gelled system with PS and hydrolyzed collagen was used to replace ice-cream fat, resulting in whiter creams ($\Delta E < 6$) with physical properties of similar or improved quality compared to the control, probably due to an enhanced protein network formation [175]. Thus, a promising option was obtained to decrease SFA content, even including healthy compounds such as PS and collagen. Additionally, PS-GO oleogel-based emulsions were adequate options to replace milk cream [177]. Increasing PS-GO content improved ice-cream quality characteristics compared to unstructured oil-based ice cream and showed similar or even better parameters than those of the control. Additionally, not only SFA was highly diminished ($\sim$80%), but also the incorporation of PS and GO could be beneficial to offer a healthier product.

Aiming to obtain an adequate ice-cream base from whey protein and LC, composition and process parameters for emulsion formation were optimized [176]. The use of LC-added high oleic palm oil, instead of coconut or soybean oil, and the structurant-oil system microfluidization generated the most suitable structures. Reformulated ice cream presented viscosity and some texture properties similar to those of the control, although SFA content was significantly reduced.

Vegan creams from stable high UFA oleogels were formulated not only to replace milk fat but also to reduce SFA commonly provided by palm oil [178]. Soy-based emulsion physicochemical properties were not substantially modified by processing conditions nor by fat phase. CLW oleogel and milk fat generated emulsions with similar rheological and physical instability parameters, but different from those of dairy cream. However, palm oil-based emulsion was the most structurally unstable. Additionally, oleogels produced by using polysaccharides-protein Pickering emulsions were tested as fat replacers in low-fat (5–15%) vegan cream formulations [179]. Appearance and texture attributes of reformulated creams were rated at acceptable values, being the lowest fat level the most similar to the control.

26.7 Other Food Applications

In addition to mimicking the performance of solid fats as food ingredients, structuring oils with high UFA content has also been explored to provide technological functions, such as shelf-life prolongation of ready-to-eat foods, quality improvements of fried foods, and development of tailor-made foods through 3D printing, among others (Table 26.6).

Coatings are restricted-permeability films usually used to protect perishable foods from different external agents. Among the various coating options, edible films stand out for their reduced waste generation and consumer acceptance. W/O emulsions formulated using vinegar and MG-sorbitan tristearate (STS) oleogels were used to coat roasted eggplants by immersion and subsequent freezing [182]. Coating efficiency was related to film wettability and greasiness, improving with increasing STS:MG ratio, although a high MG amount was needed to enhance emulsion consistency. Film appearance was semitransparent and did not change with the freezing process. Essential oil-enriched EC-MG oleogel-based emulsions were applied by spraying over sausages [183]. Antibacterial protection was demonstrated only for low and medium viscosity EC emulsion-based films, which improved sausage edibility by 100 and 220% or 66 and 166% compared with untreated products or control (unstructured oil-based film), respectively.

Additionally, films can be used to improve packaging technological aspects. In this sense, a BW oleogel-oil bilayer structure was used to promote yogurt sliding out from its container [181]. The oleogel layer on the base material enabled subsequent oil adhesion and, consequently, appropriate oil layer formation, which greatly improved viscous liquid product sliding (Fig. 26.7a). Moreover, this effect was maintained during long-term storage, without affecting product aroma and stability.

Frying mediums are usually preferred with minimum PUFA and middle or high SFA. CRW oleogels from canola or soybean oils were tested as frying mediums for different products such as chicken breast [184], flour-based snacks [185], and instant noodles [186]. In all cases, sample fat content was reduced by at least 16% when frying in structured oil rather than free oil, regardless of the structurant level used. This effect could be attributed to changes induced in the surface texture of the fried product, generating smaller pores by frying in oleogel than in oil and, therefore, achieving lower oil retention capacity in the final product. Oxidative stability was

Table 26.6 Oleogel technological functions

Food application	System	Gelator (wt% in system)/oil	Replaced fat (wt % replacement)	Reference
Coating	Oleogel	BW (10)/sunflower	*n.a*	[181]
	Oleogel	MG:STS (0.6–11:0.6–11)/olive:sunflower (27.0:62.0, 28.7:65.8)	*n.a*	[182]
	O/W emulsion	EC:MG (1.2:2)/cinnamon essential	Cinnamon essential oil (100)	[183]
Deep frying medium	Oleogel	CRW (5, 10)/canola	Canola oil (100)	[184]
	Oleogel	CRW (5, 10, 15)/soybean	Soybean oil (100)	[185]
	Oleogel	CRW (5, 10)/soybean	Soybean or palm oil (100)	[186]
Gummies	Oleogel	Stearic acid (10)/canola	*n.a*	[187]
Foams	Oleogel	MG:PS (3–10:0–10)/canola	*n.a*	[188]
Noodles	Oleogel	CLW (10)/soybean	*n.a*	[189]
3D printing material	Oleogel	BW (2–25)/sunflower	*n.a*	[190]
	Oleogel	MG:PS (10–20:20–50)/HOSO	*n.a*	[191]
	Oleogel	MG:PS (10:20)/HOSO	*n.a*	[192]
	Oleogel	EC:PEG (11:1–5)/MCT	*n.a*	[193]
	Oleogel	PS:LC (6–28:4–20)/sunflower	*n.a*	[194]

BW beeswax, *CLW* candelilla wax, *CRW* carnauba wax, *EC* ethylcellulose, *HOSO* high oleic sunflower oil, *LC* lecithin, *MCT* medium chain triglycerides, *MG* saturated monoglycerides, *n.a* not applicable, *n.s* not specified, *PEG* polyethylene glycol monostearate, *PS* phytosterols, *STS* sorbitan tristearate

maintained or improved with respect to controls. Although there were some differences in color and appearance (Fig. 26.7b), all snacks were generally well accepted by consumers [185].

The use of oleogels in other applications, such as foams [188], noodles [189], gummies (Fig. 26.7c) [187], and inks for 3D printing [190–194] has contributed positively to some product characteristics, demonstrating the wide range of options available for their usage.

26.8 Conclusions

Although a step behind oil structuring, during the last years, the application of oleogel-based systems in some goods has advanced significantly, with particular emphasis on replacing HF to improve FAP, but also applied to maintain or improve some physicochemical, structural, or sensory characteristics of foods and even their containers. Additionally, oleogel-based systems have the advantage of serving as carriers of other nutritional compounds, which is enhanced with greater versatility when such systems are formed by simultaneous hydrophobic and hydrophilic

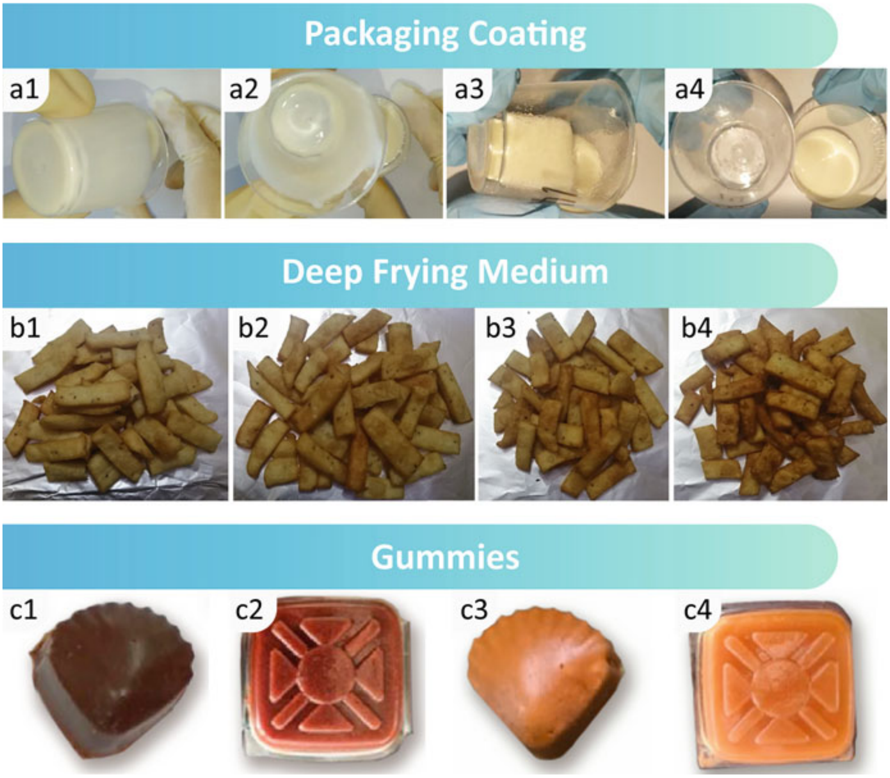

Fig. 26.7 Appearance of products of different oleogel-based system technological applications: (**a**) packaging with (a1, a2) unstructured oil and (a3, a4) coating from beeswax oleogel, reproduced from [181] with permission from Elsevier; (**b**) products fried in (b1) soybean oil and carnauba wax (CRW) oleogels with (b2) 5 wt% CRW, (b3) 10 wt% CRW, and (b4) 15 wt% CRW, reproduced from [185] with permission from Elsevier; and (**c**) gummies from stearic acid oleogel-based systems enriched with (c1, c2) doum juice and (c3, c4) orange juice, reproduced from [187] with permission from Springer-Nature under the terms of the Creative Commons CC BY 4.0 licence

phases—as emulsion, templated-based, or bigel systems. Therefore, current applications will continue to be evaluated as feedback to improve system formulation—with a high expectation on gelling using multicomponents—and processing. Generally, with an appropriate choice of gelling system and fat substitution level, formulations could be tailored to meet specific raw material and/or other end-use requirements and maintain the desired mechanical properties. However, at this point, it is important to emphasize that not all property differences found between structured oils and control fats are transmitted to reformulated foods. The effect of oleogel-based system incorporation on food properties depends not only on lipid replacement level and oleogel structuring system but also on several factors, such as specific formulation and raw materials—type and purity—even their interactions, replaced fat, total lipid content, processing and storage conditions, and temperature at which the products are consumed and tested. This makes predicting general trends extremely challenging, so it is suggested to look for the best conditions for each particular formulation.

While an active evaluation of oleogel-based system applications in the food sector has been demonstrated throughout this chapter, there are some gaps that have yet to be explored in sufficient depth. Instrumentally measured values, although very valuable as a guide for experimentation, do not always have the ability to reflect consumer behavior or preference. Consequently, the optimization of oleogel-based system properties must consider the effect of their incorporation into the target product, even including sensorial and digestibility analysis and structural and chemical stability studies during storage to confirm goal achievement. In general, oleogels and emulsions have been widely studied as fat substitutes in almost all food categories presented here. However, other system applications could offer advantages not yet examined. In addition, some of them deserve specific studies, such as microbiology stability in those where water activity is increased. Also, with a rather limited approach yet, the growing demand for vegan, gluten-free, and/or lactose-free foods makes it necessary to evaluate HF substitution in the corresponding products. Promising results are expected to assist food industries in adopting oleogel-based systems as fat replacers or for developing health-beneficial products. Additionally, based on the current knowledge, new applications may emerge.

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