THE ARCHITECTURE OF FAT

Oleogels, Structured Emulsions and the Reinvention of Food Texture

From Lipid Crystallisation and Interfacial Engineering to Nutritional Reformulation, Industrial Performance and European Food Law

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Abstract

Solid fat is not merely a nutrient fraction in a formula. It is an engineered material whose crystal organisation, melting trajectory, oil immobilisation, interfacial behaviour and interaction with other food constituents determine much of the texture and stability of commercial foods. The substitution of saturated-fat-rich shortenings or tropical fat fractions with liquid unsaturated oils therefore creates a structural deficit that cannot be corrected simply by reproducing total lipid content. Oleogels, emulsion gels, high-internal-phase emulsions, particle-stabilised systems and hybrid bi-gels have emerged as different ways of addressing this deficit. This critical interdisciplinary review examines their molecular and colloidal assembly, processing sensitivity, oxidative chemistry, gastrointestinal behaviour and evidence of product-level performance. Specific emphasis is placed on original 2026 studies of confectionery fillings and chocolate spreads, which support feasibility within defined experimental matrices but do not warrant broad claims of industrial or clinical equivalence. A decisive legal distinction is drawn between a physically structured oil that is technologically plausible and a finished food whose component ingredients, additives, product designation and marketing claims are lawful in the European Union. Directive 2000/36/EC introduces a special limitation for cocoa and chocolate products; Regulations (EC) No 1333/2008 and (EU) 2015/2283 require examination of functional ingredient and manufacturing identity; Regulation (EC) No 1924/2006 governs claims concerning reduced saturated fat; and Regulation (EU) 2026/1825 updates contaminant provisions for 3-MCPD and glycidyl fatty-acid esters. The paper proposes a stage-gated industrial validation framework linking lipid specification, network mechanics, tribology, oxidative shelf life, sensory response, compositional compliance and product economics. The strategic opportunity is not to make every food low-fat but to build **functionally designed lipid phases** whose structure and composition are independently measurable, stable and legally defensible.

Keywords: oleogel; oleogelation; emulsion gel; structured lipid; saturated fat; crystallisation; oil migration; cocoa fillings; chocolate; bakery; oxidation; tribology; rheology; lipid digestion; European food law; novel foods; contaminants.

1. The fat that consumers experience is a material, not an assay result

A nutritional table can describe a food as containing a specified quantity of fat and saturated fatty acids. It cannot explain why a biscuit fractures cleanly, why a cream filling remains spreadable at 18 °C, why a chocolate coating contracts during cooling, or why an apparently stable bar hardens after eight weeks. These characteristics depend on the spatial arrangement of lipids and solids, not simply on the relative percentages of fatty acids obtained after analytical transesterification. The food technologist consequently works with at least two distinct objects: a chemical lipid composition and a physically structured fat phase. They are coupled, but they are not synonymous.

Many conventional food fats contain a solid crystalline fraction at ambient temperature. The distribution of triacylglycerols (TAGs), the proportion of solid fat as temperature changes, crystal polymorphism, particle interaction and shear history collectively establish plasticity. Saturated fatty acids often contribute to this behaviour because they occur in TAG species with melting characteristics that facilitate network formation. Yet it is chemically imprecise to treat the quantity of saturated fat as a direct measure of mechanical strength. The placement of fatty acids on the glycerol backbone, TAG compatibility, thermal history and microstructure also influence the finished material. Nor is every saturated-fat-rich food functionally interchangeable with another.

For decades the simplest route to a product with solid-fat functionality was to select an appropriate naturally solid fat, a fractionated lipid or a modified TAG composition. Industrially produced trans fats were previously another means of obtaining desirable plasticity; European regulation now tightly restricts trans-fat other than that naturally occurring in fat of animal origin. A less compositionally intrusive alternative is to retain a predominantly liquid oil and immobilise it in a three-dimensional network formed by a comparatively small proportion of structuring material. This is the premise of oleo-gelation. Recent reviews, including work published

during 2026, increasingly situate oleogels alongside emulsion gels, particle-stabilised systems and bi-gels rather than treating them as a single technology (Ali et al., 2026; *Structural Engineering of Edible Oleogels*, 2026).

The most important conceptual distinction is that **a fat phase can be made mechanically solid-like without its constituent oil becoming rich in saturated fatty acids**. Whether this distinction survives storage, oral processing, industrial heating and digestion is the substantive research question. It must be answered for each lipid network and each application. An attractive laboratory gel is not automatically an acceptable bakery shortening, and an acceptable confectionery filling is not evidence of improved cardiometabolic health.

2. Oleogels are one member of a broader family of structured lipids

An oleogel is generally a semi-solid system in which a liquid oil is immobilised within a network of a structuring agent, commonly termed an oleogelator. The oil remains the major continuous phase. Network formation may result from crystallisation and self-assembly of low-molecular-weight compounds, polymeric structures, interfacial particle interactions or templated organisation. What matters is the emergence of a sufficiently connected architecture to resist flow and retain liquid lipid under the conditions of interest.

Direct oleogelation typically requires dissolving or dispersing a structuring agent in oil under controlled heat and shear, followed by cooling or another step that permits network organisation. Waxes, selected monoacylglycerols and other lipid-compatible substances can form fine crystalline assemblies. Polymeric routes may involve ethylcellulose or other materials, but their food-law status cannot be inferred from their general chemical description or from approval for different applications. The concentration needed for a target modulus is not a universal constant: oil polarity, TAG composition, impurities, cooling rate and thermal history can make nominally identical formulations behave differently.

Emulsion-template oleogels follow a different trajectory. The oil is first structured or compartmentalised in an emulsion, allowing proteins, polysaccharides or particles to help create a network; subsequent removal of part or most of the water can yield a self-supporting oil-rich material. This route may provide functionality with reduced reliance on lipid crystallisers, but drying energy, process duration, residual moisture, microbial considerations and batch reproducibility become critical. A system that works in a laboratory freeze dryer may fail a commercial cost or throughput test.

An **emulsion gel**, by contrast, normally retains two phases: oil droplets are arrested inside a continuous gelled matrix, often aqueous. Protein and polysaccharide networks, droplet packing and droplet–matrix interactions determine texture. Such a system may be suitable for an aqueous meat analogue, dressing, dairy-type product or spread, but it is not a one-for-one substitute for an anhydrous fat in a low-water confectionery filling. Adding water can fundamentally change water activity, microbiological risk, sugar dissolution, protein hydration and migration dynamics.

High-internal-phase emulsions (HIPEs) obtain solid-like behaviour through dense packing of the dispersed phase and the mechanical consequences of droplet deformation. Particle-stabilised or Pickering emulsions exploit interfacial attachment of appropriately wetting particles. Bi-gels combine an oleogelled lipid phase and a hydrogelled aqueous phase, creating two interconnected or dispersed gel networks. These categories can overlap in practical formulations, but their continuous phases, failure mechanisms and analytical requirements differ. The 2026 review by Ali and colleagues is useful precisely because it recognises this architectural diversity in plant-based meat applications, rather than presenting every structured-oil system as an oleogel with identical performance.

Table 1. Physical architecture and the problem each lipid system is designed to solve

System	Dominant structural mechanism	Plausible food functions	Primary failure modes	Essential regulatory question
Direct crystalline oleogel	Oleogelator network immobilising liquid oil	Plasticity, spreadability, oil retention	Thermal collapse, oil leakage, recrystallisation, waxy mouthfeel	Are all gelators lawfully usable for this technological purpose and food category?
Polymeric or particulate oleogel	Polymer chains or particles establish a connected lipid network	Oil binding, extrusion compatibility	Process sensitivity, poorly controlled dispersion	Does the exact polymer or particle have an admissible food status and specification?
Emulsion-template oleogel	Emulsion-derived network subsequently concentrated or dried	Fat replacement in relatively dry matrices	Residual water, drying cost, incomplete oil immobilisation	What remains in the final ingredient and how is it legally classified?
Emulsion gel	Oil droplets immobilised within a continuous gel	Lubrication, juiciness, reduced-fat texture	Syneresis, phase inversion, microbial growth	Are emulsifiers and gelling agents permitted at the intended levels?
HIPE / particle-stabilised system	Dense droplets and/or interfacial particles	Spreadability and bite	Coalescence, processing-induced phase failure	Is the particle-stabiliser authorised and correctly labelled?
Bigel	Coupled oleogel and hydrogel structures	Dual-phase texture and active delivery research	Water migration, network mismatch, unstable sensory release	Does each constituent meet ingredient/additive/novel-food requirements?

The table presents engineering categories and investigational uses, not authorisations for any particular composition.

3. Crystallisation, rheology and the false security of a firm laboratory sample

A solid-like appearance is a necessary but insufficient condition for successful lipid replacement. Rheological characterisation should distinguish elastic storage modulus (G'), viscous loss modulus (G"), yield stress, deformation tolerance and recovery after shear. The frequency dependence of G' and G" reveals whether a material behaves like a coherent network across the mechanical conditions of processing or merely holds shape after gentle cooling. A sample that appears solid in a vial may collapse when pumped, aerated, sheared through a nozzle or held above its structuring temperature.

For a bakery shortening, the relevant failure may occur during creaming, when plastic fat must help entrap air bubbles. For a confectionery filling, it may be oil migration into a biscuit or chocolate shell, followed by changes in texture or bloom. For an extruded plant-based product, the lipid architecture may have to survive thermal and mechanical conditions and subsequently produce acceptable lubrication during chewing. There is no singular target modulus for all these products.

Differential scanning calorimetry (DSC) can characterise thermal transitions, but DSC peak positions alone do not establish the mechanical properties of the complete food. Polarised-light microscopy and, where appropriate, X-ray diffraction can provide information about crystalline network organisation; confocal microscopy may help resolve emulsion structures; controlled stress–strain and flow tests reveal how those structures withstand work. A crucial connection is frequently missing in publications: structural measurements are performed on the isolated gel, but consumer-relevant texture is measured only after the gel has been integrated into a powder-, protein- or sugar-rich product. Those are different physical environments.

An especially demanding case is cocoa butter. Its TAG composition and crystalline polymorphs underpin tempering, gloss, fracture, contraction and melting in conventional chocolate. A wax-structured oil may provide a similar apparent firmness at one temperature yet have a different solid-fat-content curve, crystallisation

pathway and oral melting profile. These differences can be decisive even when a penetrometer or simple texture test suggests equivalence. Accordingly, the proposal to use an oleogel in a **chocolate-flavoured filling** cannot be generalised to substitution of cocoa butter in a legally defined **chocolate** product. There is both a physical reason and a legal reason for separating those applications.

Industrial selection should therefore map each functional target to a measured property. “Oil retention” should be specified as leakage after defined temperature cycles and centrifugal or compression loads. “Spreadability” should be measured at realistic serving temperatures and shear rates. “Heat stability” should identify not only the maximum temperature achieved but the duration, cooling profile and post-cycle mechanical recovery. A study conducted after 24 hours at 20 °C cannot by itself establish performance in a six-month European distribution chain.

4. Oxidative stability: a new microstructure does not repeal lipid chemistry

Unsaturated oils offer opportunities to change the fatty-acid profile of a food, but they are not chemically immune to oxidation. The susceptibility of a lipid phase depends on its degree and pattern of unsaturation, endogenous antioxidants, trace metals, oxygen exposure, interfaces, moisture, temperature and processing history. The formation of hydroperoxides during the initiation stages of oxidation and their decomposition into aldehydes and other secondary products can compromise flavour and nutritional quality long before a visible physical defect develops.

Oleogelation can alter oxidation kinetics in opposing directions. The network may restrict molecular motion, limit oil exposure or help retain antioxidants; alternatively, it may change oxygen transport, concentrate pro-oxidants near interfaces or necessitate heating steps that accelerate deterioration. There is no sound general rule that a gelled oil is more oxidatively stable than the same oil before gelation. The structure, the oil and the processing pathway must be compared directly.

A 2022 study of short-dough biscuits prepared with oleogel systems and green-tea extract investigated physicochemical performance and oxidative stability over 15 weeks. More recent work in 2026 has studied oleogel-fortified biscuits and lipid preservation during storage. These are useful proofs of process- and matrix-dependent feasibility, not evidence that every oil network prevents oxidation or that a particular botanical extract is automatically authorised in every product. Claims concerning antioxidants require separate legal analysis and cannot be inferred from a reduction in laboratory peroxide value (*The effect of green tea extract and oleogels*, 2022; *Comparative Evaluation of Functional Biscuits*, 2026).

A defensible analytical programme should select parameters according to the raw oil and product. Peroxide value and p-anisidine value may offer complementary information, but neither alone fully represents oxidation in a complex baked or cocoa-containing matrix. Headspace volatiles such as hexanal can be informative for appropriate oils; conjugated diene measurements, sensory rancidity and specific aldehydes may be warranted. The interpretation of a composite index such as TOTOX must be qualified if its constituent methods are not fit for the matrix. Oxygen in packaging headspace, dissolved oxygen during mixing, protective atmosphere and metal contamination from raw materials should also enter the experiment.

Oxidative failure is not only an analytical issue. A product can maintain acceptable yield stress while developing off-flavour, and another can retain acceptable flavour while losing oil to the package. Both defects matter commercially, but the release specification and corrective action will differ. The scientific merit of a novel structuring material therefore rests on the joint optimisation of oxidation, migration and sensory performance rather than on a favourable photograph of a stable gel.

5. What the 2026 original studies actually demonstrate

The most instructive recent evidence comes from formulation experiments in confectionery. Ferdaus and colleagues (2026) investigated oleogels prepared using corn or sesame oil and sunflower wax or glycerol monostearate, with different structurant concentrations. From a wider experimental set, four formulations were advanced to chocolate-cream-filling testing. Their reported findings favoured certain monostearate-based systems, including a formulation containing 6% structurant, for sensory acceptability, texture and thermal performance relative to the particular shortening comparator. The value of this study is not a universal statement that glycerol monostearate is the optimal oleogelator. Rather, it establishes a concrete structure–formulation–sensory connection in a defined filling system, with material selection shaped by multiple experimental outputs (Ferdaus et al., 2026).

A separate 2026 study in *Journal of Food Science* investigated creams incorporating oleogels structured with monoglycerides or beeswax. The investigators selected formulations based on oil binding, thermal and morphological performance before examining shortening-replacement levels. Replacement experiments covered a range from 25% to 75% of the shortening component. The reported shifts in saturated-fat content and texture support the feasibility of partial replacement. They do not demonstrate that every substitution level, lipid source, processing line or shelf-life duration is acceptable. Indeed, the very need to screen multiple replacement proportions shows why the word “replacement” must not be interpreted as automatic one-to-one equivalence (*A Novel Approach to Reducing Saturated Fatty Acids*, 2026).

Another paper first published in November 2026 assessed rice-wax- and glyceryl-monostearate-based alternatives in chocolate spreads, addressing not just firmness but tribological behaviour. This is an important methodological improvement: a successful spread must shear under a knife, coat the oral surfaces and release aroma during consumption. Tribology can detect differences missed by bulk rheology, especially where lubrication is governed by saliva, particles and an oil-rich boundary layer. Nevertheless, it remains necessary to demonstrate that a tribological difference predicts consumer preference in the actual formulation (*From Oleogel Structure to Product Performance*, 2026).

Taken together, these studies justify an engineering programme; they do not establish a single commercial formulation, a clinical outcome or a blanket EU legal status. Their applicability is limited by differences in oil source, wax or monoglyceride identity, dose, product solids, storage conditions and sensory methodology. Comparative research is most useful when the reference is a realistic industrial shortening, not only an unstructured liquid oil that was never expected to function adequately.

Table 2. Evidence appraisal of selected 2026 studies

Research context	What was examined	Evidence supported	What remains unproven
Chocolate cream fillings, Ferdaus et al.	Oil/structurant combinations; texture, oil binding, thermal response and sensory testing	Certain experimentally selected oleogels can perform acceptably in the specified filling	Industrial reproducibility, all-category legality, long-term health benefit
Filling creams, *Journal of Food Science*	Monoglyceride/beeswax systems; partial shortening replacement	Formulation-dependent reduction of saturated-fat-rich shortening can be feasible	Complete replacement, universal shelf life, broad consumer acceptance
Chocolate spreads, *Journal of Food Science*	Rice-wax and monostearate structuring; mechanical and tribological attributes	Oral lubrication and bulk texture deserve joint measurement	Predictive consumer model, cross-category generalisation
Oleogel biscuits, 2026	Processing and stored-product quality	Selected networks can maintain desirable physical or oxidation attributes	Universal oxidation protection or validated disease-risk reduction

The evidence is primarily food-engineering evidence. It should not be presented as replicated randomised human clinical evidence.

6. The mouthfeel problem: why tribology matters alongside texture analysis

A rheometer measures deformation within a sample under imposed conditions; a human mouth processes a dynamic mixture of fragmented food, saliva, mucin, proteins, sweeteners and lipid phases. During chewing, the system passes through several regimes of lubrication. Large-scale texture, particulate fracture, mixed lubrication and boundary-layer behaviour may all influence the consumer's perception of creaminess, fattiness, dryness or pastiness. An oleogel that mimics the bulk hardness of a solid fat may nevertheless create an unexpected waxy coating on the tongue, a delayed melt or an excessively persistent film after swallowing.

Oral temperature is not sufficient as a single design criterion. Food is distributed through the mouth over time; surface temperature, local shear, saliva dilution and particle dissolution evolve during consumption. An apparent melting transition near 37 °C can be promising, but it cannot substitute for time–intensity sensory evaluation and realistic oral-processing measurements. Confectionery systems are particularly sensitive because sweetness, aroma release and particle size interact with fat lubrication. Reducing saturated fat may simultaneously change aroma partitioning and perception of cocoa bitterness, even when sugar and cocoa powder levels are held constant.

The choice of structurant must therefore be evaluated as a sensory decision, not merely a network-strength decision. A gelator producing an extremely high G' at 20 °C might be undesirable if its melting and fracture behaviour creates a waxy sensation. A weaker gel may deliver better consumer acceptance but unacceptable storage leakage. The correct design is a compromise among texture, phase retention, oral release and supply reliability, measured under predefined product-specific conditions.

An integrated research plan could combine texture profile analysis, rotational and oscillatory rheometry, a tribometer using appropriate food-relevant contact surfaces, trained descriptive panels and consumer testing. Correlations between instrumental parameters and perception should be developed from replicate batches, tested in a separate formulation set and reported with uncertainty. A multivariate model trained and validated on the same samples is not evidence of predictive capacity. The distinction between explanatory modelling and independent prediction is essential for companies proposing "AI-designed" lipid architectures.

7. Digestion and metabolic interpretation: the boundaries of the evidence

Replacing a saturated-fat-rich ingredient with a lipid phase richer in mono- and polyunsaturated fatty acids can be nutritionally meaningful. Yet the dietary effect depends on the fatty acids actually consumed, the rest of the recipe, the amount of product eaten and the food that is displaced in the diet. A product with the same total fat content as its comparator may reduce saturated fat without reducing calories. Lipids still provide the standard energy contribution used under EU nutrition-declaration rules, irrespective of whether they are arranged in an oleogel or an emulsion gel.

Structured lipid phases can alter exposure to digestive lipases. Droplet size, interfacial composition, accessibility of triacylglycerols and the rate at which the gel network disintegrates may modify in-vitro lipolysis or the release of lipophilic compounds. But a slower in-vitro release profile is not necessarily healthier. It might influence absorption kinetics in one setting, reduce bio-accessibility of a desirable vitamin in another, or have no clinically meaningful effect in humans. Mechanistic studies of simulated digestion should therefore be treated as pathway investigations, not as proof of improved metabolism (*Assembly mechanisms and structure design of oleogels and bi-gels*, 2026).

A proposed clinical hypothesis could concern postprandial lipaemia after a meal containing two compositions with matched energy and total fat but contrasting lipid architecture. A different trial would be required to assess the effect of a dietary intervention replacing saturated fatty acids with unsaturated fatty acids over several weeks. Neither hypothesis is answered by a texture experiment in a chocolate filling. Endpoints such as triglyceride incremental area under the curve, lipoprotein concentrations, tolerability or body weight need

distinct designs and durations. Changes in food texture can also alter appetite or portion selection, so realistic exposure must be measured.

It is commercially tempting to describe structured oils as “healthy fats”. That language conceals at least four independent propositions: the source oil has a favourable fatty-acid composition; the structuring agent and manufacturing route are lawful and safe; the finished food has an improved nutritional composition; and the resulting diet produces a relevant physiological effect. The first may be established by chromatography, the second by regulatory and safety dossiers, the third by compositional analysis, and the fourth by human evidence appropriate to the claimed effect. None of these determinations substitutes for the others.

8. Four food matrices, four distinct engineering problems

8.1 Cocoa creams, spreads and confectionery fillings

Fat-rich creams often contain suspended sugar, cocoa and sometimes milk or protein solids in a continuous lipid phase. The product must flow during manufacturing yet resist oil migration in storage. Its oral melt must be consistent with consumer expectations, and its structure must tolerate the intended transport temperatures. Here, oleogels are relevant candidates because they can immobilise unsaturated liquid oils while preserving an oil-continuous architecture. The most useful screening metrics are oil-binding capacity, yield stress, solid-fat-content response, migration into adjacent bakery or chocolate layers, particle dispersion and sensory finish.

However, “chocolate cream filling” and “chocolate” are not interchangeable legal categories. A filling or spread can be formulated differently from a product reserved under Directive 2000/36/EC, subject to its own applicable composition and labelling rules. The legal route should be established before work begins, not after a prototype has achieved desirable rheology. In many cases an application to a legally defined chocolate filling, rather than to the chocolate shell, is the technically and regulatorily more credible first development.

8.2 Bakery fats and shortening replacement

Bakery shortening serves multiple purposes. It affects aeration, dough handling, gluten development, starch interactions, spread, crumb softness and shelf life. The functional target differs among laminated pastry, biscuits, cakes and filled wafers. A network that performs well in a biscuit may fail to provide the plasticity or gas-cell stabilisation necessary for cake batter. High-shear mixing, oven temperature and cooling introduce phase changes absent from room-temperature oleogel characterisation.

The most informative experimental approach varies oleogel replacement independently from water and total fat. Mixing all three changes together obscures causal inference. For a biscuit, measurements could include spread ratio, fracture force, moisture uptake, sensory crispness, oil migration and oxidative stability. For a cake, batter specific gravity, overrun, volume and crumb pore distribution are crucial. It is not enough to report a desirable fatty-acid profile if the product becomes harder, drier or less acceptable during storage.

8.3 Plant-based proteins and meat analogues

Structured lipid phases can contribute juiciness, visible fat inclusions and lubricity in plant-based meat. Unlike an anhydrous confectionery filling, these matrices are usually water-rich and undergo significant thermal and mechanical processing. Emulsion gels, particle-stabilised emulsions or hybrid structures may be preferable to direct wax oleogels, depending on the desired release behaviour. Protein denaturation and network formation interact with lipid retention, and a formulation that appears stable before cooking may lose oil and water during heating.

Experimental work should measure cooking loss, lipid loss, expressed moisture, fracture, tribology and consumer perception alongside protein digestibility and microbial stability. In 2026, the structured-lipid literature identified these multi-phase architectures as promising for plant-based meat but also noted unresolved scaling

and sensory challenges (Ali et al., 2026). A protein analogue must still qualify for lawful marketing according to its actual ingredients and consumer presentation.

8.4 Protein bars and composite coatings

Protein bars couple a concentrated solid matrix with plasticisers, carbohydrate binders and frequently a fat-based or compound coating. Structural replacement of the coating fat can influence viscosity during enrobing, setting rate, adhesion, cracking and storage migration into the centre. Protein-bar hardening over time is already a complex kinetic process; altering the coating's oil migration may either improve or worsen the composite product. Because bars often face warm retail distribution and long shelf lives, temperature-cycling tests are especially relevant.

For a prototype, the technical specification should separate the coating and the bar core. Relevant outcomes include enrobing viscosity at process temperature, film thickness, crystallisation or setting kinetics, fat bloom, adhesion, bite, oxidative markers, packaging interactions and real-time storage stability. The use of an oleogel in an isolated confectionery cream provides a rationale to investigate this application, not a demonstration that the complete coated bar will pass industrial validation.

9. European regulatory architecture: physical innovation and legal identity

9.1 A lawful oil does not automatically confer lawful status on every structurant

In the EU, legal classification is substance- and use-specific. Regulation (EC) No 1333/2008 concerns food additives deliberately used for technological purposes, within authorised food categories and applicable conditions. Regulation (EU) No 231/2012 specifies requirements for authorised additives. A wax used for a permitted surface-glazing function may not automatically be usable at much higher concentrations as a bulk structural agent inside every filling. The presence of an E number is not a universal licence for any technological purpose or dose. Product developers must examine each material's actual function, use level, food category, specification and applicable restrictions.

Some structuring materials are ordinary food ingredients; others may be additives; and a new source, modified substance or manufacturing process may raise novel-food questions under Regulation (EU) 2015/2283. A broad description such as "plant wax", "cellulose structurant" or "fermentation-derived lipid" does not resolve the legal classification. Where uncertainty exists, evidence of consumption before 15 May 1997 and the process-specific criteria of the Novel Food Regulation must be reviewed. Nor should the appearance of a structurant in a non-European scientific study be mistaken for its EU authorisation.

9.2 Cocoa and chocolate are a special case, not a generic confectionery exception

Directive 2000/36/EC reserves specified cocoa and chocolate product definitions. Under Article 2 and Annex II, certain vegetable fats other than cocoa butter may be incorporated into designated chocolate products subject to stringent restrictions, including a 5% limit in the relevant calculation, maintenance of minimum cocoa solids and cocoa-butter requirements, and labelling conditions. Annex II contains compositional and process criteria for permitted cocoa-butter-equivalent fats; it is not a general permission for arbitrary oleogels, wax structures or enzymatically modified TAG systems. In particular, the Annex II criteria exclude enzymatic modification of the triglyceride structure for the listed cocoa-butter equivalents.

The consequence is commercially significant. An innovative cocoa-flavoured cream can be viable as a filling, spread or appropriately designated confectionery component while being unsuitable for replacing cocoa butter in a product sold under a protected chocolate denomination. The assessment must consider the exact product definition, ingredient composition, label and country of sale. The correct regulatory question is not whether the alternative fat is plant-based but whether its incorporation is compatible with the reserved product identity.

9.3 Nutrition and health claims require finished-product calculations

Under Regulation (EC) No 1924/2006, “reduced saturated fat” is not established merely because an oleogel contains less saturated fatty acid than a shortening ingredient. The relevant authorised condition concerns the **sum of saturated fatty acids and trans-fatty acids** in the marketed food: it must be at least 30% lower than in a similar product, and the trans-fatty-acid content must be equal to or lower than in that comparator. A lawful comparison also requires the general requirements of the Regulation to be met. The reference product and the finished formulation must be justified, and the comparison cannot be reconstructed opportunistically after testing.

For example, consider a purely illustrative 100 g finished-food comparison. A conventional formulation contains 10.0 g saturated fatty acids and 0.2 g trans fatty acids; a redesigned formulation contains 6.8 g saturated fatty acids and 0.1 g trans fatty acids. The combined concentrations are 10.2 and 6.9 g, respectively. The relative reduction is (10.2 − 6.9)/10.2 = **32.4%**. On this numerical criterion alone, the candidate clears the 30% reduction condition, and trans-fat has not increased. It would still require an appropriate comparator, reliable analytical data, compliant wording and fulfilment of the remaining legal requirements. These numbers are hypothetical and are not INTABIOTECH product data.

“Low saturated fat” is a different, much more demanding claim: the sum of saturated and trans fatty acids must be no more than 1.5 g/100 g in solids or 0.75 g/100 mL in liquids, and must not provide over 10% of energy. It would be misleading to treat a substantial percentage reduction in a confectionery cream as proof that the cream is “low in saturated fat”. Likewise, a saturated-fat reduction does not automatically make a food low-energy or low-fat. The fat quantity and energy calculation must be evaluated separately under Regulation (EU) No 1169/2011.

A health claim concerning replacing saturated fatty acids with unsaturated fatty acids has its own subject and conditions under the EU authorised-claims framework, including Commission Regulation (EU) No 432/2012. The existence of such a claim does not authorise unrestricted cardiovascular language or a therapeutic assertion for an investigational oleogel formulation. The final food, its composition and the exact conditions must be checked in the current Union register.

9.4 Trans fats, process contaminants and the 2026 amendment

Commission Regulation (EU) 2019/649 sets an upper limit of **2 g of trans fat per 100 g of fat** in foods intended for the final consumer or supply to retail, excluding trans-fat naturally occurring in fat of animal origin. It also contains a specific business-to-business information obligation in relevant circumstances. Oleogelation may help avoid creating trans fats by partial hydrogenation, but it does not remove the need to verify the actual fatty-acid profile of oils, shortenings and finished products.

Regulation (EU) 2023/915 establishes maximum levels for a range of food contaminants, including glycidyl fatty-acid esters and the sum of 3-MCPD and its fatty-acid esters in relevant oil and food categories. Commission Regulation (EU) **2026/1825 of 29 July 2026** amended these provisions, including provisions relevant to compound foods containing vegetable oils and new or revised limits for specified categories. Some requirements concerning infant foods and oils intended for their manufacture have a stated application date of 1 January 2027. Consequently, a dossier prepared in November 2026 must distinguish rules already applicable from future-dated requirements and must not apply one undifferentiated threshold across all products. The concentration and regulatory treatment of contaminants in a compound food require case-specific assessment of its constituent oils, category and applicable calculation rules.

This issue is independent of the attractiveness of the lipid network. A technically stable oleogel can fail because a refined oil or other ingredient does not meet the applicable contaminant specification. Conversely, an oil satisfying contaminant limits does not automatically meet a wax or additive authorisation requirement. Analytical compliance is a chain, not a single certificate.

Table 3. European regulatory decision map for structured-lipid ingredients

Regulatory question	Core instrument	Required determination	Common but invalid shortcut
May this agent structure the lipid phase in this food?	Regulation (EC) 1333/2008; Regulation (EU) 231/2012	Classification, function, food category, dose and purity	"It has an E number, therefore any use is permitted"
Is the new material or manufacturing route a novel food?	Regulation (EU) 2015/2283; Union list 2017/2470	Exact identity, historical use and production process	"Its chemical family is traditional"
May the finished product be sold as chocolate?	Directive 2000/36/EC	Reserved definition, fat identity, composition and labelling	"It tastes like chocolate"
Can reduced saturated fat be claimed?	Regulation (EC) 1924/2006	Verified SFA+TFA reduction and comparable product	"The source oil has less saturated fat"
Are trans-fat levels controlled?	Regulation (EU) 2019/649	Quantified relevant trans-fat and B2B disclosures where applicable	"Oleogels never contain trans fats"
Does the oil and finished food meet contaminant limits?	Regulation (EU) 2023/915, as amended by 2026/1825	Applicable product category, analytical data, dates	"Any compliant oil makes every compound food compliant"
Are nutritional declarations truthful?	Regulation (EU) 1169/2011	Finished-product fat, saturates, energy and ingredients	"The formulation spreadsheet is a validated label"

10. A structure–composition–law design framework for industrial development

A robust R&D programme should start with a design brief stating the **function to be replaced**. "Replace palm oil" is a procurement objective; "replace a 25 °C plastic shortening while retaining oil migration below a defined limit and reducing finished-product SFA+TFA by at least 30%" is a testable scientific brief. The latter identifies both material and nutrition constraints. It does not presuppose a particular structurant or that the threshold will ultimately justify a marketing claim.

Gate I - Legal and raw-material identity. Record botanical origin, refining history, TAG and fatty-acid profiles, antioxidants, contaminants, allergen status, material specifications and traceability. Review the proposed structurant's EU admissibility for its intended function before commencing extensive pilot development. A legally unavailable ingredient should not be selected as the commercial lead merely because it performs well in research.

Gate II - Oil and network characterisation. Analyse the constituent oil by a suitable validated fatty-acid method, with special attention to saturated and trans fractions. Determine peroxide value, appropriate oxidation markers and contaminant compliance. Prepare oleogel candidates across defined process histories. Characterise thermal transitions, rheology, oil binding and microstructure. A formulation should be reproducible across independently prepared batches, not just one carefully handled laboratory sample.

Gate III - Finished-matrix performance. Test the selected networks inside the actual food, including the intended cocoa or protein powders, soluble solids, emulsifiers, process shear and packaging. Define objective pass/fail criteria for thermal cycling, oil migration, processability and texture. Compare with a realistic existing commercial reference. Testing only the isolated gel against plain oil is insufficient.

Gate IV - Sensory and oral processing. Use trained descriptive panels to measure attributes such as melting, waxiness, lubrication, cocoa flavour release, pastiness and aftertaste; follow with consumer acceptance where appropriate. Include storage-aged samples, not only fresh prototypes. Sensory blindness to formulation identity and randomised serving order will reduce interpretive bias.

Gate V - Stability and food safety. Conduct real-time shelf-life studies, informed but not replaced by accelerated stress tests. Oxidative and physical processes often have different temperature dependencies; a single acceleration factor should not be assumed. For emulsion gels or bigels, establish moisture, water activity

and microbiological controls. Use packaging permeability and transport conditions representative of actual distribution.

Gate VI - Nutritional and legal sign-off. Validate finished-product nutrient declarations, calculate comparative nutrition claims, review reserved names and ingredient statements, and check applicable contaminant rules at the intended market-launch date. Regulatory decisions should be recorded against the exact batch specification and product formula so that supplier substitution cannot silently invalidate them.

Gate VII - Economics and scale-up. Determine cost per kilogram of saleable final product, not merely cost per kilogram of the source oil. Include structurant, heating and cooling, additional homogenisation, filtration, drying where used, waste, changeover losses, quality testing, packaging, process throughput and rejected lots. A technically feasible lipid phase may still be commercially inferior if it requires costly processing or imposes a narrow temperature window incompatible with the customer's production line.

Table 4. Proposed minimum industrial evidence package

Evidence domain	Suggested measurements	Decision enabled
Lipid composition	GC-based fatty-acid profile; relevant TAG characterisation; SFA and TFA	Does the formulation change nutritional composition?
Material structure	DSC; rheology; microscopy; oil-binding/migration	Does the selected network provide the necessary physical function?
Product processing	Yield stress at process temperature; pumping; setting; rework tolerance	Can the system operate reliably at commercial scale?
Oxidative stability	Peroxide value plus appropriate secondary oxidation markers; sensory rancidity	Is shelf life supported for this oil and matrix?
Oral performance	Tribology, descriptive sensory profile, consumer acceptance	Is the product pleasant after structural reformulation?
Safety and legality	Contaminants; additive authorisation; novel-food status; reserved category	Can the exact material and finished product be marketed in the EU?
Nutrition and claims	Finished-product assay, comparator, threshold calculation, exact wording	Is the intended communication lawful and substantiated?
Scale-up and economics	Batch variation, throughput, process energy, waste and final unit cost	Is the candidate commercially scalable?

11. A worked formulation experiment: cocoa filling with reduced saturated fat

Consider a fictional industrial brief for an oil-continuous cocoa filling used in a bar or wafer. The existing formulation uses a solid shortening and meets a defined target for extrusion, spreading or deposition at 30–35 °C, with a shelf life of at least six months. The goal is not necessarily to reduce total fat, but to lower the combined SFA+TFA content while preserving texture and oil retention. The numerical targets below are illustrative research criteria and do not represent an existing INTABIOTECH formulation.

An initial screening set might compare two food oils with different unsaturation and oxidation behaviour, subject to supply and regulatory suitability, against several candidate networks. A two-stage design is preferable. In the first stage, limited concentrations of clearly admissible structuring materials would be screened for isolated-network yield stress, thermal resilience, oil-binding capacity and oxidation. In the second stage, only the better-performing systems would enter the cocoa filling with all non-fat ingredients, solids loading and processing conditions held constant. This prevents preliminary sensory variability from obscuring whether the oil phase itself is technically capable.

The comparator should not be a simple oil-only control. It should include the current industrial shortening and, if commercially useful, an alternative already accepted lipid system. A legitimate test would measure firmness and spreadability on the day of manufacture and after storage at several temperature conditions. Oil migration through the interface into the adjacent wafer or coating should be measured by a repeatable method. Consumer

sensory panels should examine fresh and stored products, because the initial impression of creaminess may change as fat migration and crystallisation evolve.

The statistical plan should prespecify primary product-function endpoints, such as oil migration or temperature-dependent yield stress, before examining secondary nutritional outcomes. Each experimental lot must be independently produced. The analysis should account for processing batch as a source of variability, rather than treating repeated measurements of the same jar as independently manufactured replicates. A response-surface model might guide subsequent optimisation, but only if its predictions are checked on new batches that were not used to fit the model.

Commercial feasibility must include the legally available structurant and the relevant product denomination. If the same oil network were instead intended for a legally defined chocolate coating, the technical brief would require a separate investigation under Directive 2000/36/EC, not a simple transfer of the cream-filling recipe. This distinction can redirect a company towards a marketable product earlier and avoid investment in a formulation that cannot be sold under its intended name.

12. Where computational methods and AI can contribute, and where they cannot

Structured-fat optimisation has many interacting variables: oil TAG distribution, structurant concentration, cooling trajectory, shear, water content, non-fat solids, package oxygen, storage conditions and sensory preferences. These produce a high-dimensional design space that lends itself to statistical design of experiments, mechanistic modelling and, eventually, machine learning. A useful computational platform could connect measurable descriptors of a lipid network to product-level outcomes such as yield stress, migration, oxidation and sensory waxiness. This is a legitimate industrial application of multivariate methods.

However, data scarcity is a serious obstacle. Many published studies examine a narrow formulation set, a small number of batches and product-specific methods. A model trained on such data may learn the experimental design rather than transferable food physics. Combining datasets without harmonising rheological units, thermal histories, oil compositions and sensory scales can manufacture spurious associations. A high internal cross-validation score is particularly unconvincing when related samples from the same batch appear in both training and testing partitions.

The scientifically disciplined route is to record structured metadata, predefine a performance target, separate training and validation by manufacturing lot and test external prediction across an additional matrix or facility. Mechanistic constraints can improve a model: for example, conservation of lipid mass, limits on structurant concentration, known thermal transitions and legal admissibility should not be ignored merely because a statistical model predicts favourable texture. Regulatory infeasibility is a hard exclusion criterion, not a cost penalty that can be outweighed by a high sensory score.

AI may accelerate selection of formulations to test; it does not replace the obligation to measure oxidative stability, run actual industrial conditions, determine legal status or verify human outcomes. An especially promising use is to connect experimental uncertainty with decision-making: if the predicted improvement in texture is small compared with batch variability, the next experiment should focus on reproducibility rather than on announcing the existence of a superior lipid architecture.

13. Safety questions beyond the expected fat profile

The safety dossier should consider hazards arising from the entire material and process. For refined oils, relevant parameters may include contaminant limits, oxidation state and supplier traceability. For structuring agents, identity, purity, residual solvents where relevant, migration of process impurities and any additive- or novel-food-specific conditions must be assessed. When direct oleogelation involves heating, the actual temperature–time

profile should be examined for degradation products and loss of antioxidant protection. The absence of hydrogenation is not proof of an absence of all process hazards.

For emulsion gels or bigels, the presence of an aqueous phase opens additional questions concerning water activity, preservative hurdles, microorganism growth, packaging and post-process contamination. A product with an oleogelled lipid phase might be low in water, but its water-rich counterpart cannot inherit the same shelf-life assumptions. Similarly, a product that incorporates an unfamiliar plant wax must not be described as hypoallergenic or allergen-free simply because the main oil is plant-derived. Source, purification and cross-contact require appropriate evaluation.

Biodegradability, renewability or lower land-use pressure are environmental propositions requiring their own evidence. A source oil may be associated with a different carbon, water or land footprint, but the result depends on agriculture, refinery conditions, transport, processing energy, waste and system boundaries. Replacing a fractionated tropical fat with a highly processed oleogel is not automatically an environmental improvement. A life-cycle assessment should define the functional unit as equivalent food performance, not merely one kilogram of raw oil, because shelf-life losses and rejected product can dominate an apparently small ingredient-level advantage.

14. Discussion: precision is a burden of proof, not a marketing adjective

The technical attractiveness of oleogels lies in separating mechanical functionality from a high solid-fat fraction. That separation is real and experimentally tractable. It allows companies to ask whether the texture of an existing product could be recreated through network design while retaining a more unsaturated oil. But the resulting formulation still inhabits a tightly constrained space. It may be fragile under temperature cycling, require a structurant without an appropriate EU food-category authorisation, oxidise during storage, impair oral melting or create unacceptable manufacturing cost. Any of these can defeat the commercial proposition.

The industrial literature is moving beyond isolated networks towards product-level investigations, including the 2026 confectionery and spread studies. This is a positive transition. Yet a critical gap remains between laboratory feasibility and independently replicated market performance. Large-scale studies should document not only best-performing formulations but failure conditions, batch variability, equipment compatibility and consumer acceptance after realistic storage. Negative results are useful because they reveal which combinations of lipid composition and process architecture are intrinsically unsuitable.

For an ingredient-development company, a differentiated service would not consist of selling a generic “oleogel”. It would consist of specifying a lipid architecture for a defined customer’s food: source oil and lawful structurant, critical material attributes, validated thermal and mechanical behaviour, finished-product nutritional composition, legal denomination, sensory performance and shelf-life evidence. The first business advantage is therefore methodological. A platform that knows when a system fails can be more valuable than one that displays a large catalogue of promising prototypes without traceable validation.

The cocoa and confectionery opportunity is particularly instructive. An oleogel may be appropriate for a cream filling or a compound coating without being an authorised substitute for cocoa butter in reserved chocolate categories. A nutritional improvement in saturated-fat composition may also coexist with unchanged energy density. Both distinctions should be communicated precisely. They do not weaken the technology; they define the conditions under which it can be responsibly commercialised.

15. Conclusions

The reinvention of fat functionality is fundamentally a problem of material architecture. Oleogels and structured emulsions offer different ways of controlling the flow, deformation, oil retention and oral behaviour of food lipids without relying exclusively on the conventional solid-fat fraction. The 2026 evidence demonstrates that selected

systems can be integrated successfully into certain confectionery creams, spreads and bakery matrices. It does not demonstrate universal replacement of shortening, clinically validated metabolic benefit or automatic regulatory admissibility.

Three linked judgements should govern the next development cycle. First, the food must function: the lipid network must survive processing, distribution and eating. Second, the nutritional result must be measured in the finished food: a favourable source oil does not alone establish a lawful reduction claim, a calorie reduction or a health benefit. Third, the commercial material must comply with European food law: product-specific additive permissions, novel-food assessment where relevant, the special cocoa/chocolate rules and contaminant requirements, including the 2026 amendment, must all be evaluated independently.

These obligations point to a productive research agenda. Define the fat phase by chemical identity and network physics; challenge it under realistic manufacturing conditions; quantify oxidation and migration throughout shelf life; test oral experience in the actual food; confirm the finished product's nutritional characteristics; and determine lawful ingredient use and communication before market launch. An industrial company that can connect these stages reproducibly will be positioned to develop more credible lipid-reformulation systems than one that promises only the replacement of saturated fat by liquid oil. **The objective is not merely a softer nutritional label, but a better-engineered food whose underlying evidence survives scrutiny.**

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