Organogelation: it’s food application

Abstract
There is growing evidence that dietary fat may link to risk of a number of chronic disorders, such as coronary heart disease or type 2 diabetes. Due to increasing consumer awareness to healthy and risk of saturated fat, food manufacturers are switching on novel technologies. One of novel technology is organogelation/oleogelation i.e. structuring of edible oils. The unique physical, functional, and nutritional properties of edible oil organogels has caught the eye of the food and pharmaceutical industries. These organogels are formed upon self assembly of surfactant-like small molecules into crystalline fibers at very low concentrations (wt 2%), which could be exploited for a variety of purposes in food products, from the manufacture of spreads to the solubilization, stabilization and delivery of lipid-soluble nutraaceuticals. The use of oleo gels in the food industry is still in its infancy, but the potential is significant. This paper reviews about the traditional and current strategies of structuring oleo gels, types of gelators used in structuring and food applications.

Keywords: food, gelator, novel, nutraceutical, oleogel, organogel, pharmaceutical

Introduction
Gels with the ability to immobilize a liquid phase are structures of three-dimensional network. These types of gels consist of two parts, gelling agent (network forming) and liquid solvent phase (hydrophilic or hydrophobic). However, depending on the polarity of the liquid immobilized within the networked structure, gels may be termed either as hydro gels (polar solvent-water) or organogels (organic solvent). An organ gel can be defined as an organic liquid entrapped within a thermo-reversible, anhydrous and structured viscous-elastic material by a three-dimensional gel network, also referred to as oleo gels if the organic phase is edible oil. This simply means transformation of a liquid oil into a ‘gel-like’ structure with viscous-elastic properties. This gel network is formed by the self-assembly of a relatively low concentration of low molecular weight compounds organogelator molecules, which are capable of gelling organic solvents.2,3

The replacement of solid fat in food products (fat mimetic) is the potential of oleo gels and the improvement in the nutritional profile of foods. Oleo gels can also be used in a variety of applications such as in cosmetics (to prevent oil leakage), pharmaceutical and biotechnology (for the encapsulation and/or controlled release of hydrophobic bioactive molecules). It can also be used to entrap organic solvents in plastic and paint industries.4 The use of oleo gels in the food industry is just beginnings, but the potential is substantial.2,4

Structuring of oleo gels and current strategies
According to fundamental research perspective, organogelation with many characteristics is an interesting topic as it brings up important questions in basic research of study such as crystallization, surface chemistry/physics and materials science. One of these characteristics is that most organogels are relatively low-molecular weight compounds.5-9 Organogel formations use those types of compounds which have ability to form a network. The ability of these compounds to gel a solvent is believed to be a balance between the solubility and insolubility of the gelator within the solvent. It should not be to either more soluble or insoluble. It should be relatively insoluble so that it can crystallize meso structures and soluble such that it can interact with solvent molecules.2 Two structuring methods are used for oleo gel productions. These are traditional and non-traditional structuring methods. Currently non-traditional structuring method is frequently used.

Traditionally, oil structuring of TAG molecules is based on the molecular configurations and diversity of the molecules which permits the tailoring of physical properties of the fat according to the desired functionality of food product by using the modified processing methods or by changing the chemistry of the material. The majority of fat products available to the consumer are structured by a colloidal network of crystalline TAG particles. TAG that contains cis or Trans fatty acids will face a decrease in solubility on cooling below its melting point at ambient temperature. It is considered that saturated fatty acids become dissolve in unsaturated TAG phase and this leads to the formation of solid nuclei of TAG which further grow into crystalline nanoparticles or spherulitic particles. Organization of these spherulitic particles into arbitrary flocs establishes noncovalent interactions between fat crystal networks, which provide physical functionality to the fat material. The quantity of crystalline matter is an important parameter for determining the characteristics of the lipid material.7,8,10

A nontraditional way to structure oil with reduced levels of Trans and saturated fatty acids is based on the use of structurants which have potential of replacement of the natural network of TAG structure in the native fat. Now, several strategies have been developed to structure oil using different structurants, also termed gelators (Figure 1). These structurants should have following characteristics such as: food grade, economical, versatile, and efficient as lipid and matching physical properties to be used in food applications. Through molecular self assembly of particle or fibril crystallization can potentially lead to the formation of three-dimensional gel network which mimic TAG crystallization (Figure 1A & 1B). Such mechanism can be found in waxes, monoglycerides and diacylglycerol, fatty acids and fatty alcohols. The use of high concentration of particle filler could also lead to the configuration of a colloidal network that leads to the formation of oleo gels (Figure 1C).11 Additional way to structuring oil is Liquid crystalline mesophases (Figure 1D).12 Recent studies have explored the use of macromolecules as a gelator for vegetable oils such as ethyl cellulose (EC) (Figure 1E).13

Abbreviations: TAG, tri acyl glycerol; DAG, di acyl glycerol; MAG, mono acyl glycerol; EC, ethyl cellulose

MOJ Food Process Tech. 2017;4(2):66–72.
Types of organogelators

Organogelators can be classified into two systems: crystal particle systems and self-assembly systems. In former the organogelator involves crystal particles occurring through nucleation and subsequent growth of crystals in the oil phase, whereas in the latter involves a molecular-level self organization in the oil phases. Another classification differentiates organogelators between polymeric and low-molecular weight organogelators. Low-molecular weight organogels will be further categorized into two groups: lyotropic phases and crystalline dispersions. The main difference between the two is that lyotropic phases include three parts (structuring, hydrophobic and hydrophilic solvent) whereas crystalline dispersion includes two parts (structuring and solvent). Examples of low molecular weight organogelators are TAG, DAG, MAG, fatty acids, fatty alcohols, waxes, wax esters and sorbitannostearate. Polymeric organogelators show the promising ability in food sector as many are inexpensive and food grade compared with the former. Among them, ethyl cellulose shows particularly interesting potential. Different strategies of structuring organogels using different types of gelators are summarized in Table 1.

Table 1 Different strategies, type of gelator and their examples

| S. No | Type of strategy       | Type of gelator                              | Example                                                                 | References |
|-------|------------------------|-----------------------------------------------|------------------------------------------------------------------------|------------|
| 1     | Crystalline material   | n-Alkanes                                     | n-Tetracosane (C-24), n-octacosane (C-28), n-dioctacosane (C-32), n-hexatriacosen (C-36) | 29         |
|       |                        | Carbamates                                    | Carbamates with alkyl side chains of different lengths                | 30         |
|       |                        |                                               | Candelilla wax                                                        | 31–34      |
|       |                        |                                               | Rice bran wax                                                         | 14,32      |
|       |                        |                                               | Sunflower wax                                                         | 32,35      |
|       |                        |                                               | Carnauba wax                                                         | 32         |
|       |                        |                                               | Beewax                                                                | 35,36      |
|       |                        |                                               | Sugarcane                                                            | 33         |
|       |                        | Fatty acids and fatty alcohol                 | Stearic acid, stearyl alcohol                                         | 37–41      |
|       |                        | Hydroxylated fatty acids                      | 12-Hydroxystearic acid                                                | 17,34,42–45|
|       |                        | Monoacylglycerol (MAG)                        | Variety                                                               | 46–48      |
|       |                        | Diacylglycerol (DAG)                          | Dipaimin and distearin                                                | 49         |
|       |                        | Triacylglycerol (TAG)                         | High and low melting temperature TAG mixtures                          | 50,51      |
|       |                        | γ -Oryzanol/ phytosterol mixtures             | Sterol ester γ - + phytosterol (dihydrocholesterol, cholesterol, β-sitosterol, cholestanol, stigmastanol) | 52–55      |
|       |                        |                                               | Sphingolipids                                                         | 56,57      |
|       |                        |                                               | Lecithin                                                              | 58         |
|       |                        |                                               | Lecithin+sorbitantristearate                                          | 3,59       |
|       |                        |                                               | Lecithin and sitosterol                                                | 60         |
|       |                        |                                               | Lecithin and α-tocopherol                                              | 61         |
|       |                        |                                               | Sorbitannostearate (SMS)                                              | 62,63      |
|       |                        |                                               | Sorbitannostearate (SMP)                                               | 64         |
|       |                        |                                               | N-Lauroyl L-alanine and N-stearoyl L-alanine                           | 65         |
Organogelation: it’s food application

Copyright: ©2017 Kaushik et al.

Citation: Kaushik I, Jain A, Grewal RB, et al. Organogelation: it’s food application. MOJ Food Process Technol. 2017;4(2):66–72. DOI: 10.15406/mojfpt.2017.04.00089

Table Continued

| S. No | Type of strategy | Type of gelator | Example | References |
|-------|------------------|----------------|---------|------------|
| 2     | Particle filler  | Silica particles | Ethyl-cellulose (EC) | 20 |
| 3     | Liquid Crystalline mesophase | | Isocyanate-functionalized methylecellulose (MC) | 68 |
| 4     | Macromolecules | Polymer | Cellulose derivative mixtures (EC, MC and α-cellulose) | 69,70 |
|       |                  |                | Chitin, chitosan, and acylated derivatives | 71 |
| 5     | Dried protein systems | | B-Lactoglobulin | 72,73 |
|       | Dried water soluble polysaccharide network | | Hydroxypropyl methylecellulose (HPMC), methylecellulose (MC), xanthan gum | 74,75 |
|       | Other            | Dried protein/ polysaccharide network | Gelatin and xanthan gum | 76 |
|       | Shellac          |                | NA      | 77,78 |

Food applications of oleo gels

Applied and basic research into the organogelation of hydrophobic solvents has skyrocketed in recent years. From an applied research perspective, organogels have a wide range of “futuristic” uses such as tissue engineering, template synthesis of inorganic nanostructures, biosensors and nanowires, to name a few. With regards to foods, cosmetics and pharmaceuticals, the applications in which there is the greatest interest relates the ability of organogels to structure non-polar solvents. In food sector, alteration of TAG structure is the main impetus which is provided by organ gel research.9,17 The availability of alternative structurants produce food products with reduced content of saturated fatty acids and zero Tran’s fatty acids. The various food applications of oleo gels are mentioned below or summarized in Table 2.

Table 2 Food applications of different types of gelators

| S. No | Type of gelator | Food application | Reference |
|-------|----------------|------------------|-----------|
| 1     | 12-hydroxystearic acid | Reduced syneresis in peanut butter | 79 |
|       |                  | Prevent oil migration in cream-filled chocolate confection | 2,4,21,22,60,81 |
|       |                  | Controlled release of β-carotene | 26 |
|       | Ethyl cellulose | Prevent oil migration in cream fillings and cookies | 5 |
|       | Ethyl cellulose (15%) or ethyl cellulose (11%) and sorbitan monostearate (3.67%) | Reduction of saturated fat in frankfurters | 16 |
|       | Shellac | Prevent oil migration in chocolate paste | 75 |
| 4     | Sunflower wax and soya bean oil | Reduction of saturated fat in margarine | 83,84 |
| 5     | Rice bran wax | Reduction of saturated fat content in ice cream | 85 |
| 6     | Monoacylglycerols (0.5-2.5%), fatty alcohols (0.5-2.5%) or soy lecithin (2.5%) | Meat suspensions | 86,87 |
| 7     | Lecithin | Controlled release of nutraceuticals | 19,88 |
| 8     | Soy lecithin and palm oil oleo gel | Controlled release of nutraceuticals | 89 |
| 9     | Monostearin | Controlled release of curcuminoids | 90,91 |
| 10    | Carnauba wax and monoglyceride | Reduction of saturated fat in margarine | 36 |
Controlled release of nutraceuticals

Controlled release technology is now widely used in the pharmaceutical industries, where drugs are either encapsulated by materials or incorporated into tablets that are designed specifically to delay or control the rate of drug release into the bloodstream after oral administration. Since many important bioactive compounds are hydrophobic, it has been proposed that organogels be used to increase the solubility and control the release of non-polar pharmaceuticals. Various studies are listed in Table 2 which summarized that organogelation is today’s novel alternative method which provides different application in bakery, frying and confectionary products with low or zero Tran’s fatty acids. In addition, based on the results described above, it was hypothesized that the gel network might also control the release of the lipids during digestion and therefore incites a more gradual or steady physiological response. For ex. Ethyl-cellulose (EC) is a new organogelator that is suitable for structuring vegetable oils. The glass transition temperature of EC is about 140°C and at this temperature EC dissolves completely and forms gel upon cooling. Therefore, EC is a good choice for replacing the saturated fats in different foods such as beef frankfurters.

Emulsions

Due to the amphiphilic nature of some low molecular weight organogelator molecules, it has been proposed that they may be able to simultaneously stabilize and impart structure to water-in-oil emulsions. In other words, it may be possible to immobilize water droplets within a continuous gelled oil phase. With the proper formulation and processing conditions, organ gelled emulsions may have application as low-fat spreads or to control the release of both hydrophilic and hydrophobic bioactive compounds. This is a relatively new concept and accordingly, there is very little scientific literature published on this topic.

Conclusion

Based on the evidence described in this review, it is clear that edible oil gel-based delivery systems are relatively new in food and these are three-dimensional networked structures with the ability to immobilize a liquid phase. Organogels can be formed by traditional and non-traditional methods but nowadays these are formed by non-traditional structuring technologies. It is summarized that various types of gelators are used during its formation such as fatty acids, alcohols, organic acids, waxes etc. It demonstrates significant futuristic promise and potential for a wide variety of applications in both food and pharmaceutical industries. However, much more work will be required to develop this technology into marketable consumer products.

Acknowledgements

None.

Conflict of interest

The author declares no conflict of interest.

References

1. Sagiri S, Behera B, Rafanan R, et al. Organogels as matrices for controlled drug delivery: a review on the current state. Soft Materials. 2014;12(1):47–72.
Organogelation: it's food application

2. Hughes NE, Marangoni AG, Wright AJ, et al. Potential food applications of edible oil organogels. Food Science and Technology. 2009;20:470–80.

3. Pernetti M, van Malssen KF, Floter E, et al. Structuring of edible oils by alternatives to crystalline fat. Current Opinion in Colloid and Interface Science. 2007;12:221–231.

4. Marty S, Baker K, Dibildox-Alvarado E, et al. Monitoring and quantifying of oil migration in cocoa butter using a flatbed scanner and fluorescence light microscopy. Food Research International. 2005;38:1189–1197.

5. Stortz TA, Zetzl AK, Barbut S, et al. Edible oree gels in food products to help maximize health benefits and improve nutritional profiles. Lipid Technology. 2012;24(7):151–154.

6. Davidovich-Pinhas M, Barbut S, Marangoni AG. Development, Characterization, and Utilization of Food-Grade Polymer Oleo gels. Annu Rev Food Sci Technol. 2016;6:75–91.

7. Terech P, Weiss RG. Low molecular mass gelators of organic liquids and the properties of their gels. Chemical Reviews. 1997;97(8):3133–3160.

8. Adullahal AJ, Weiss RG. Organogel and low molecular mass organic gelators. Advanced Materials. 2007;12(17):1237–1247.

9. Co ED, Marangoni AG. Organogels: an alternative edible oil-structuring method. Journal of the American Oil Chemists' Society. 2012;89(5):749–780.

10. Nairne SS, Marangoni AG. Relating structure of fat crystal networks to mechanical properties: a review. Food Research International. 1999;32:227–248.

11. Whitby CP, Omink AJ. Rheological properties and structural correlations in particle-in-oil gels. Adv Powder Technology. 2014;25:1185–1189.

12. Nikiforidis CV. Lipid mesophase nanostructures. Edible Nanostructures in particle-in-oil gels. 2015. p. 114–143.

13. Dey T, Kim DA, Marangoni AG. Ethylcellulose oleogels. See Marangoni & Garti. 2011. p. 295–311.

14. Dassanayake LSK, Kodali DR, Ueno S. Formation of oleogels based on edible lipid materials. Current Opinion in Colloid & Interface Science. 2011;16:432–439.

15. Duffy N, Blong HK, Beindorff C, et al. Organogel-based emulsion systems, micro-structural features and impact on in vitro digestion. Journal of the American Oil Chemists' Society. 2009;86(8):733–741.

16. Zetzl AK, Marangoni AG, Barbut S. Mechanical properties of ethylcellulose oleogels and their potential for saturated fat reduction in frankfurters. Food Funct. 2012;3(3):327–337.

17. Rogers MA, Wright AJ, Marangoni AG. Nanostructuring fiber morphology and solvent inclusions in 12-hydroxystearic acid/canola oil organogels. Current Opinion Colloid Interface Science. 2009;14(1):33–42.

18. Ghosh V, Ziegler GR, Anantheswaran RC. Fat, moisture, and ethanol migration through chocolates and confectionary coatings. Critical Reviews in Food Science and Nutrition. 2002;42(6):583–626.

19. Smith KW, Cain FW, Talbot G. Effect of nut oil migration on polymorphic trans-formation in a model system. Food Chemistry. 2006;102:656–663.

20. Ziegler GR, Shetty A, Anantheswaran RC. Nut oil migration through chocolate. The Manufacturing Confectioner. 2004;84:118–126.

21. Rogers MA, Wright AJ, Marangoni AG. Engineering the oil binding capacity and crystallinity of self-assembled fibillar networks of 12-hydroxystearic acid in edible oils. Soft Matter. 2008;4(7):1483–1490.

22. Rogers MA, Wright AJ, Marangoni AG. Post-crystallization increases in the mechanical strength of self-assembled fibillar networks are due to an increase in network supramolecular ordering. Journal of Physics D: Applied Physics. 2008;41(21):215–210.

23. Felt O, Buri P, Gurny R, Chitosan: a unique polysaccharide for drug delivery. Drug Dev Ind Pharm. 1998;24(11):979–993.

24. Romoscanu AI, Mezzenga R. Emulsion-templated fully reversible protein-in-oil gels. Langmuir. 2006;22(18):7812–7818.

25. Turner S, Federici C, Hite M, et al. Formulation, development and human in vitro-in vivo correlation for a novel, monolithic controlled-release matrix system of high load and highly water-soluble drug micro. Drug Dev Ind Pharm. 2004;30(8):797–807.

26. Wright AJ, Pietrangeli C, MacNaughton A. Influence of simulated upper intestinal parameters on the efficiency of beta carotene micellarisation using an in vitro model of digestion. Food Chemistry. 2008;107(3):1253–1260.

27. Marangoni AG, Garti N. Edible Oleogels: Structure and Health Implications. Urbana, USA: AOCS Press; 2011.

28. Patel AR, Cludts N, Sintang MDB, et al. Polysaccharide-based oleogels prepared with an emulsion-templated approach. Chem Phys Chem. 2014;15(16):3435–3439.

29. Abdallah DJ, Weiss RG. n-Alkanes gel n-alkanes (and many other organic liquids). Langmuir. 2000;16(2):352–355.

30. Moniruzzaman M, Sundararajan PR. Low molecular weight organogels based on long-chain carboxamates. Langmuir. 2005;21(9):3802–3807.

31. Alvarez-Mirte FM, Toro-V´azquez JF, Moscoso-Santill´an M. Shear rate and cooling modeling for the study of candelilla wax organogels` rheological properties. Journal of Food Engineering. 2013;119:611–618.

32. Blake AI, Co ED, Marangoni AG. Structure and physical properties of plant wax crystal networks and their relationship to oil binding capacity. Journal of the American Oil Chemists' Society. 2014;91(6):885–903.

33. Rocha JCB, Lopes JD, Mascarenhas MCN, et al. Thermal and rheological properties of organogels formed by sugarcane or candelilla wax in soybean oil. Food Research International. 2013;50:318–323.

34. Toro-Vazquez JF, Morales-Rueda J, Torres-Martinez A, et al. Cooling rate effects on the microstructure, solid content, and rheological properties of organogels of amides derived from stearic and (R)-12-hydroxystearic acid in vegetable oil. Langmuir. 2013;29:7642–7654.

35. Jana S, Martinis S. Effect of high-intensity ultrasound and cooling rate on the crystallization behavior of beeswax in edible oils. J Agric Food Chem. 2014;62(11):10192–10202.

36. Ogutucu M, Yilmaz E. Oleogels of virgin olive oil with carnauba wax and monoglyceride as spreadable products. Grasas Y Aceites. 2014;65(3):1–11.

37. Daniel J, Rajasekharan R. Organogelation of plant oils and hydrocarbons by long-chain saturated FA, fatty alcohols, wax esters, and dicarboxylic acids. Journal of the American Oil Chemists' Society. 2003;80(5):417–421.

38. Gandolfo FG, Bot A, Marangoni AG. Engineering the oil binding capacity and crystallinity of self-assembled fibillar networks of 12-hydroxystearic acid in edible oils. Soft Matter. 2008;4(7):1483–1490.
40. Sagiri SS, Singh VK, Pal K, et al. Stearic acid based oleogels: a study on the molecular, thermal and mechanical properties. Mater Sci Eng. 2015;48:688–699.

41. Schaink HM, Van Malssen KF, Morgado-Alves S, et al. Crystal network for edible oil organogels: possibilities and limitations of the fatty acid and fatty alcohol systems. Food Research International. 2007;40(9):1185–1193.

42. Co E, Marangoni AG. The formation of a 12-hydroxy docosaeiac acid/vegetable oil organogel under shear and thermal fields. Journal of the American Oil Chemists’ Society. 2002;79(4):529–544.

43. Gao J, Wu S, Emge TJ, et al. Nanoscale and microscale structural changes alter the critical gelator concentration of self-assembled fibrillar networks. Crystal Engineering and Communication. 2013;15:4507–4515.

44. Liu C, Corradini M, Rogers MA. Self-assembly of 12-hydroxydocosaeiac acid molecular gels in mixed solvent systems rationalized using Hansen solubility parameters. Colloid and Polymer Science. 2015;293(3):975–983.

45. Wu S, Gao J, Emge TJ, et al. Solvent-induced polymorphic Nanoscale transitions for 12-Hydroxydocosaeiac acid molecular gels. Cryst Growth and Des. 2013;13(3):1360–1366.

46. Chen C, Terentjev EM. Monoglycerides in oils. See Marangoni & Garti; 2011. p. 173–201.

47. L’opez-Martinez A, Morales-Rueda JA, Dibdibooz-Alvarado E, et al. Comparing the crystallization and rheological behavior of organogels developed by pure and commercial monoglycerides in vegetable oil. Food Research International. 2014;64:946–957.

48. Pieve SD, Calligaris S, Co E, et al. Shear nanostructuring of monoglyceride organogels. Food Biophysics. 2010;5(3):211–217.

49. Pernetti M, van Malssen KF, Floter E, et al. Structuring of edible oils by alternatives to crystalline fat. Current Opinion in Colloid and Interface Science. 2007;12:221–231.

50. Higaki K, Koyano T, Hachiya I, et al. In situ optical observation of microstructure of β-fat gel made of binary mixtures of high-melting and low-melting fats. Food Research International. 2004;37:2–10.

51. Higaki K, Sasakiya K, Koyano T, et al. Physical analyses of gel-like behavior of binary mixtures of high- and low-melting fats. Journal of the American Oil Chemists’ Society. 2003;80(3):263–270.

52. Bot A, Agterof WGM. Structuring of edible oils by mixtures of β-oryzanol and related phytosterols. Journal of the American Oil Chemists’ Society. 2006;83(6):513–521.

53. Bot A, Veldhuizen YSI, den Adel R, et al. Non-TAG structuring of edible oils by mixtures of high- and low-melting fats. Food Research International. 2003;37:2–10.

54. Calligaris S, Mirolo G, Pieve SD, et al. Effect of oil type on formation, structure, and thermal properties of γ-oryzanol and β-steroid-based organogels. Food Biophysics. 2014;9(1):69–75.

55. Rogers MA, Wright AJ, Marangoni AG. Ceramide oleogels. See Marangoni & Garti; 2011. p. 221–234.

56. Rogers MA, Wright AJ, Marangoni AG. Oil organogels: the fat of the future? Soft Matter. 2009;5:1594–1596.

57. Scartazzini R, Luisi PL. Organogels from lecithins. J Phys Chem. 1988;92(3):829–833.

58. Pernetti M, van Malssen K, Kalnin D, et al. Structuring edible oil with lecithin and sorbitan tri-stearate. Food Hydrocolloids. 2007;21:855–861.

59. Han LJ, Li L, Zhao L, et al. Rheological properties of organogels developed by sitosterol and lecithin. Food Research International. 2013;53:42–48.

60. Nikforidis CV, Scholten E. Self-assemblies of lecithin and α-tocopherol as gelators of lipid material. RSC Advances. 2014;4:2466–2473.

61. Peyronel F, Marangoni AG. In search of confectionary fat blends stable to heat: hydrogenated palm kernel oil stearin with sorbitan monostearate. Food Research International. 2014;55:93–102.

62. Singh VK, Pramanik K, Ray SS, et al. Development and characterization of sorbitan monostearate and sesam oil-based organogels for topical delivery of antimicrobials. AAPS Pharm Sci Tech. 2014;16(2):293–305.

63. Shah DK, Sagiri SS, Behera B, et al. Development of olive oil based organogels using sorbitan monopalmitate and sorbitan monostearate: a comparative study. Journal of Applied Polymer Science. 2013;129(2):793–805.

64. Motulska A, Lafleur B, Moulin-Hoarau AC, et al. Characterization and biocompatibility of organogels based on L-alanine for parenteral drug delivery implants. Biomaterials. 2005;26(31):6242–6253.

65. Cegla-Nemirovsky Y, Aserin A, Garti N. Oleogels from glycerol-based lyotropic liquid crystals: phase diagrams and structural characterization. Journal of the American Oil Chemists’ Society. 2015;92(3):439–447.

66. Libster D, Aserin A, Garti N. Oleogels based on non-lamellar lyotropic liquid crystalline structures for food applications. See Marangoni & Garti. 2011. p. 235–269.

67. Gallego R, Arteaga JF, Valencia C, et al. Rheology and thermal degradation of isoycinate functionalized methyl cellulose-based oleogels. Carbohydr Polym. 2013;98(1):152–160.

68. Sanchez R, Franco JM, Delgado MA, et al. Rheological and mechanical properties of oleogels based on castor oil and cellulose derivatives potentially applicable as bio-lubricating greases: influence of cellulose derivatives concentration ratio. Journal of Industrial and Engineering Chemistry. 2011;17:705–711.

69. Sanchez R, Franco JM, Delgado MA, et al. Thermal and mechanical characterization of cellulose derivatives-based oleogels potentially applicable as bio-lubricating greases: influence of ethyl cellulose molecular weight. Carbohydrate Polymer. 2011;83:151–158.

70. Sanchez R, Stringari GB, Franco JM, et al. Use of chitin, chitosan and acylated derivatives as thickener agents of vegetable oils for bio-lubricant applications. Carbohydrate Polymer. 2011;85:705–714.

71. Mezzenga R. Protein-templated oil gels and powder. See Marangoni & Garti. 2011. p. 271–93.

72. Mezzenga R, Ulrich S. Spray-dried oil powder with ultrahigh oil content. Langmuir. 2010;26(22):16658–16661.

73. Patel AR, Schatteman D, Lesafferb A, et al. A foam-templated approach for fabricating organogels using a water-soluble polymer. RSC Advances. 2013;3:22900–22903.

74. Patel AR, Rajarethinem PS, Gradowski M, et al. Biopolymer-based structuring of shellac oleogels: spreads, chocolate paste and cakes. Food funct. 2014;5(4):645–652.

75. Patel AR, Rajarethinem PS, Cludts N, et al. Edible applications of shellac oleogels: spreads, chocolate paste and cakes. Food funct. 2014;5(4):645–652.

76. Patel AR, Rajarethinem PS, Cludts N, et al. Biopolymer-based structuring of liquid oil into soft solids and oleogels using water-continuous emulsions as templates. Langmuir. 2015;31(7):2065–2073.

77. Patel AR, Schatteman D, de Vos WH, et al. Shellac as a natural material to structure a liquid oil-based thermo reversible soft material system. RSC Advances. 2013;3(16):5324–5327.

78. Patel AR, Schatteman D, de Vos WH, et al. Preparation and rheological characterization of shellac oleogels and oleogel-based emulsions. J Colloid Interface Sci. 2013;411:114–121.
79. Elliger CA, Guadagni DG, Dunlap CE. Thickening action of hydroxystearates in peanut butter. *Journal of the American Oil Chemists’ Society*. 1972;49(9):536–537.

80. Yoshioka S, Aso Y, Tera T. Effect of water mobility on drug hydrolysis rates in gelatin gels. *Pharm Res*. 1992;9(5):607–612.

81. Dibildox-Alvarado E, Rodrigues JN, Gioielli LA, et al. Effects of crystalline microstructure on oil migration in a semisolid fat matrix. *Crystal Growth and Design*. 2004;4(4):731–736.

82. Wood J. Reduction of saturated fat in finely comminuted and ground meat products by use of canola oil organogels and the effect on Organoleptic qualities, texture and Microstructure. *Master of Science in Food Science*. Thesis. Guelph, Ontario, Canada: University of Guelph; 2013.

83. Hwang H, Singh M, Bakota E, et al. Margarine from organogels of plant wax and soybean oil. *Journal of the American Oil Chemists’ Society*. 2013;90(11):1705–1712.

84. Hwang H-S, Kim S, Singh M, et al. Organogel formation of soybean oil with waxes. *Journal of the American Oil Chemists’ Society*. 2012;89(4):639–647.

85. Botega DCJ, Marangoni AG, Smith AK, et al. The potential application of rice bran wax oleogel to replace solid fat and enhance unsaturated fat content in ice cream. *J Food Sci*. 2013;78(9):1334–1339.

86. Lupi FR, Gabriele D, Baldino N, et al. Stabilization of meat suspensions by organogelation: a rheological approach. *European Journal of Lipid Science and Technology*. 2012;114(12):1381–1389.

87. Lupi FR, Gabriele D, Seta L, et al. Rheological design of stabilized meat sauces for industrial uses. *European Journal of Lipid Science and Technology*. 2014;116(12):1734–1744.

88. Williman H, Walde P, Luisi PL, et al. Lecithin organogel as matrix for transdermal transport of drugs. *Journal of pharmaceutical sciences*. 1992;81(9):871–874.

89. Baran N, Singh V, Pal K, et al. Development and characterization of soy lecithin and palm oil-based organogels. *Polymer-Plastics Technology & Engineering*. 2014;53(9):865–879.

90. Yu H, Shi K, Liu D, et al. Development of a food-grade organogel with high bioaccessibility and loading of curcuminoids. *Food Chemistry*. 2012;131:48–54.

91. Turnbull D, Fisher JC. Rate of nucleation in condensed systems. *Journal of Chemical Physics*. 1949;17:71–73.

Citation: Kaushik I, Jain A, Grewal RB, et al. Organogelation: it’s food application. *MOJ Food Process Technol*. 2017;4(2):66–72.
DOI: 10.15406/mojfpt.2017.04.00089