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OLEOGELS: COMPOSITION, APPLICATIONS AND FUTURE PROSPECTS

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ABSTRACT

Oleogels are semi-solid systems that can be used in food, medicine, and cosmetics. They are created by using oleogelators to structure edible liquid oils. These gels are appropriate for transdermal drug delivery, wound healing, and food reformulation because of their smooth texture, stability, and controlled release characteristics. By substituting unsaturated fats for saturated fats, oleogels in meat products enhance nutritional profiles and lower the risk of cardiovascular illnesses. The mechanical and thermal properties of oleogels are influenced by a variety of structuring approaches, including direct and indirect ways. This paper highlights the potential of oleogel in creating healthier substitutes for conventional fats by going over its composition, manufacturing methods, and uses in processed meat products and nutraceuticals. Pharmaceutical applications of oleogels include drug delivery systems, where they enhance bioavailability and provide sustained release for hydrophobic drugs. Additionally, their emollient properties make them valuable in cosmetic formulations, offering improved texture and hydration retention. Oleogels are produced using direct and indirect methods, with structural integrity influenced by components such as waxes, fatty acid derivatives, polysaccharides, and proteins.

KEYWORDS: Oleogels, semi-solid systems, transdermal formulations, oleogelation, processed meat products.

INTRODUCTION

Edible liquid oils are solidified using oleogelators to create oleogels, which are semi-solid, three-dimensional systems. Topical dose formulations known as semisolids are employed for cosmetic, protective, or medicinal purposes. When an external force is applied, semisolid dosage forms retain their shape because of their flexible characteristic. Each semisolid dose form has distinct rheological properties. Semisolids such as creams, ointments, gels, and lotions are commonly used to give topical medications. Numerous conditions, including as dermatitis, psoriasis, wound healing, and skin infections, can be treated locally using these skin-applied formulations. Semisolids can be used to transport active pharmacological ingredients (APIs) to the site of action.[1] Gels are topical or transdermal semi-solid dose formulations. They are liquid phases of aqueous colloidal suspensions that are confined in a polymeric matrix. Gels usually appear transparent or translucent, and their smooth texture makes it easy to apply them evenly across large skin areas. In addition to being used as drugs, they can also be used as lubricants.[2,3]

Oleogels are widely used in food, cosmetics, meat products and pharmaceuticals because of their stability, smoothness, and controlled release properties. Because of their highwater content, biocompatibility, and similarity to natural tissues, hydrogels are frequently used in biomedical applications such drug delivery systems, wound healing, and scaffolds for tissue creation. They provide controlled release of active substances and can be used as vehicles for transdermal medication administration.[4]

When using small amounts of oleogators or structuralants, oleogators can successfully maintain their gel-like properties and thermo-reversibility, which qualifies them for usage in food applications. These bio-based structures may have come from several oleogators networks and are made up of a network of interconnected crystals.[5,6] In addition to waxes, proteins, and polysaccharides, fatty acids (FAs) and fatty alcohols can also create OGRs. FAs, fatty alcohols, wax esters, di-esters of hydroxycinnamic acids, and triterpene alcohols are among the sub-ingredients that make up natural waxes.[7] Hydrocolloid stabilizers, such as proteins and polysaccharides, in conjunction with waxes, have formed the foundation of recent developments in indirect techniques for producing OGs.[8] Dietary fats are the most concentrated energy source and are an important macronutrient for overall health.[9] Fats greatly improve organoleptic qualities like flavor, mouthfeel, and texture in processed foods. Saturated fatty acids (SFAs) and unsaturated fatty acids (UFAs) are the two general categories into which this macronutrient falls.[10] The molecular structure of saturated fats is devoid of double or triple bonds and shows saturation with hydrogen molecules. Although they have specific uses, studies have shown that too much saturated fat can lead to cardiovascular diseases (CVDs); hence it is advised to limit consumption to less than 10% of daily calorie intake.[11]

A significant portion of the global human diet consists of meat and meat products because of their high protein content and superior nutritional value.[12] However, eating them is linked to several health problems since they contain greater concentrations of trans-fatty acids (TFA) and saturated fatty acids (SFA).[13] The prevalence of several non-communicable diseases, such as diabetes, high blood lipid levels, inflammation, endothelial dysfunction, oxidative stress, metabolic syndrome, obesity, and especially cardiovascular diseases (CVD), is linked to higher intake of saturated fats.[14]

A 2018 World Health Organization report states that approximately 45% of fatalities worldwide are attributable to CVD. The WHO mandated that saturated, trans, and total fats should not exceed 10%, 1%, and 30% of an individual's total caloric consumption, respectively, to reduce the risk of CVD.[15] Due to these health issues, the meat industry is compelled to create healthier meat products with improved fatty acid profiles to safeguard consumers' health. By substituting fat with a healthier fatty acid profile for naturally occurring animal fat in a product, technological methods can improve the fatty acid profile.[16] More MUFA and PUFA, or conjugated linoleic acid, and less SFA and TFA are included. It is also preferable to have lower cholesterol and better omega-6/omega-3 and PUFA/SFA ratios.[17] The market for these nutritious beef products is expected to grow significantly soon since consumers of the current generation are health-conscious and will choose health above price.[18] By lowering the fat level of conventional processed meat products that are high in fat, these healthy meat products can be made.[19] However, fat plays a crucial part in preserving the meat product's texture, technology, and sensory qualities as well as in oxidative stabilization and the synthesis of aroma compounds.[20] The fundamental characteristics of meat products are often negatively impacted by changes in the amount and or makeup of fat, which impacts their marketability and consumer acceptability. Accordingly, fat substitutes should be nutritionally superior to animal fat while still providing a similar structural configuration and other quality attributes to natural fat.[21]

HISTORY

The concept of a "gel" has changed since Thomas Graham proposed a vague description in 1861. A half-century later, Dr. Dorothy Jordan Lloyd noted that "the colloid condition, the 'gel,' is easier to identify than to precisely define."

The food industry was the first to use oleogels, as inventors created structural agents to solidify liquid oils. This innovation aimed to replicate the properties of solid fats in products without resorting to the use of unhealthy saturated fats. Oleogels have exciting potential in the pharmaceutical industry as drug delivery system carriers, in addition to their use in the food industry. Their capacity to improve bioavailability and control the release of active components holds the potential to completely transform the way medications are administered.

Furthermore, oleogels' emollient qualities can improve the texture and overall feel of skincare products, including lotions, creams, and other formulations used in personal hygiene and cosmetics. Oleogels are a fascinating topic for continued research and development because of their versatility, which holds tremendous potential for their usage in personal care and pharmaceuticals in the future.[22]

WHY OLEOGELS ARE USED?

When administered as an injection, oleogels can create a drug depot, making them suitable for long-term use. They may readily ensnare hydrophobic pharmaceuticals because they self-assemble to catch the liquid oil. As a result, it works well with BCS class II or IV medications, which have poor solubility in water.[23] By focusing on solubility and direct absorption in the body, BCS class II medications such as atorvastatin, carvingiol, ciprofloxacin, etc., can be utilized in oleogel formulations to boost their efficacy.[24] In contrast, solubility and permeability are the primary characteristics that need to be improved for BCS class IV medications such as amphotericin, ciprofloxacin, neomycin, etc.[25]

The goal of this review is to better understand oleogel by examining its composition and formulation, the processes that go into making it (Fig. 1 shows the conversion of liquid oils into emulsion and then into oleogel), how it is characterized, and the various uses for which it can be put.[26] The process of turning liquid oil into an ole-ogel involves adding gelling chemicals to an oil-water emulsion.

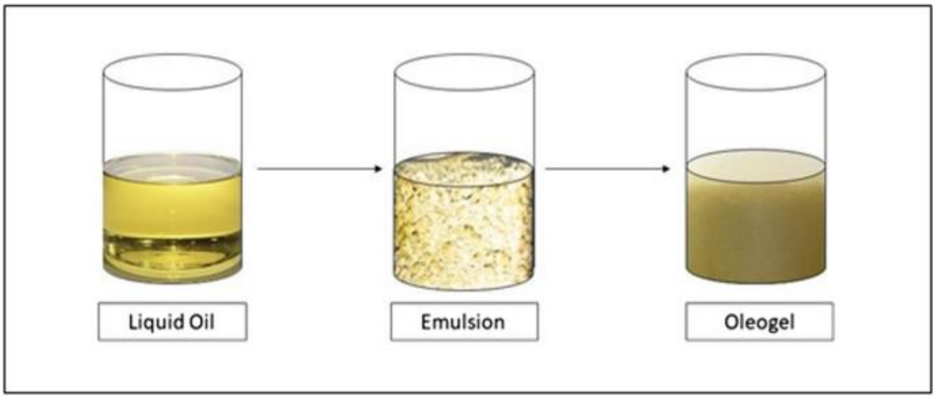


Fig. 1: Shows the conversion of liquid oils into emulsion and then into oleogel.

OLEOGELS' COMPOSITION AND FORMULATION

Edible oils are used as organic solvents to mix oleogelators such as waxes, fatty acid alcohols or esters, ethyl cellulose, phospholipids, and phytosterols to create oleo gels. The oleogelator selected and the oleo gelation technique used has a direct effect on the properties of the finished oleo gels.

The various formulating agents of oleogels are oil, waxes and shellac, triglycerol derivatives, and ceramides.

Oils

The features of oleogels, including their texture, thermal behavior, and rheology, are significantly influenced by the gelling agent and gelling solvent used in their production. In oleo gels, the oil phase has a huge impact on the gel's behavior and the absorption of lipid droplets or bioactive in the gastrointestinal phase. How oleo gels gel is influenced by their chemical makeup, namely the length of their fatty acid chains and the presence of unsaturated fatty acids.[27] An investigation on the ability of various oils, such as corn, sunflower, rice bran, and high oleic sunflower oil, to produce gel at different saturation and unsaturation levels employed wax as the gelling agent. Stronger oleogels were produced by the oils with greater saturation levels. Other oil characteristics that significantly affect the rates of gelation and crystallization of oleogels are viscosity and polarity. Oils with greater polarity produced weaker gels because of significant interactions between the gelator and solvent.[28] Furthermore, higher unsaturation leads to more spatial twisting in the oil phase, which enhances the hydrophobicity of the oil and reduces interaction energy. Stronger oleogels can be used with lower polarity, higher unsaturation levels, and higher viscosity.[29]

Olegators

The gels made by LMW Organogelators are stabilized by the solid fibers. They are made by dissolving the gelator in an organic solvent at a higher temperature and then cooling the resultant mixture to room temperature. A gel may result from an intermediate aggregation process, a random aggregation process that produces an amorphous precipitate, or a highly ordered aggregation process that produces crystals during the cooling process.[30]

Waxes and Shellac

Natural waxes can produce oleogels with small amounts of liquid oils (1-4 weight percent) by forming a three-dimensional network that absorbs oil on the network's surface and retains it inside its pores.[24] In liquid oil, wax is heated above its melting point and then cooled under quiescent or shear conditions. The chemical makeup of waxes affects the gelation behavior. This includes the relative proportions of fatty acid, fatty alcohol, and hydrocarbon chain components, which vary depending on the wax's source. Because higher saturation levels lead to better gelation, the quality of the oil is also important.

Triacyl Glycerol Derivatives

By using oil structuring systems, the triacylglycerols (TAGs) that make up the crystal network known as fat can self-assemble. Figure 2 depicts a variety of oil structuring methods. The possibility that oleogels can be created by combining TAGs with low and high melting points has been studied.[32] In contrast to the unique characteristics of high and low melting TAGs, the mixed state was discovered to have different melting/crystallization temperatures, gel properties, shape, and solid fat content. Numerous studies have examined monoglycerides (MAGs) as oil structuring agents, testing the efficacy of different MAG and oil types.[33,34,35]

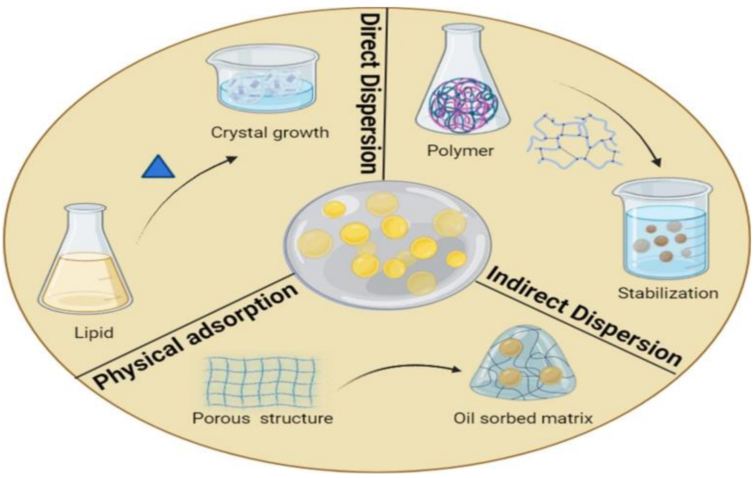


FIG. 2: Various oil structuring techniques currently in use.

Ceramides

Lipids are amidated with sphingosine to produce ceramides, the most basic sphingolipids. Depending on the length of the chain and the sugar side group, they can be synthesized chemically or enzymatically and have a range of structures. Ceramides have been linked to both the development of cancer and decreased cholesterol. By creating lamellar ceramide bilayers, ceramides can arrange canola oil and allow for the creation of persistent gels at concentrations as low as 2 weight percent.[35,36]

Pytosterols Based Oleogels

The oleogelation properties of plant sterols, such as cholestenol, ergosterol, and cholesterol levels, have been the subject of numerous investigations. They have a steroid skeleton, a hydroxyl group, and an aliphatic side chain. γ-oryzanol, a distinct phytosterol-based gelator found in rice bran, is made up of ferulic acid and triterpene alcohols, which are phytosterol esters. These gelators work in concert to create potent oleogels at low concentrations (2%). The crystal structure is influenced by vegetable oils and the ratio of γ-oryzanol to β-sitosterol, which in turn affects the rate of oil entrapment and the oil-absorbing capacity of oleogels. Canola oil's polymorphism build-up, melting temperatures, and morphological characteristics were investigated using varying ratios of γ-oryzanol and β-sitosterol.[37,38,39]

Polysaccharide-Based Oleogels

Ethyl cellulose (EC), a food-grade polymer, is commonly employed for the construction of edible oils through the application of the direct dispersion method. It is a semi-crystalline derivative of cellulose with ethyl groups instead of hydroxyl groups. The molecular mass and degree of substitution determine the functional properties of EC. Because of its semicrystalline shape and hydrophobic qualities, EC can gel in liquid oil. To encourage the formation of strong hydrogen bonds and intermolecular interactions, EC is heated above its glass transition temperature, or roughly 130°C, and then cooled. The oil is thus trapped inside the one-dimensional polymer strands, forming a three-dimensional network.[40,41,42]

Protein -Based Oleogels

The protein's hydrophilic nature restricts its ability to form networks in hydrophobic oils, hence limiting its potential application in oleogel formation. Nonetheless, two methods for protein-based oil organization have been proposed: the emulsion pattern technique and the solvent transfer methodology. Using proteins as emulsifiers, the emulsion template approach creates maximum inner-phase pickering emulsions by removing the proteins. The interfacial tension facilitates the protein's ability to form networks at their interfaces and regulate the properties of the resulting HIPE (high internal phase pickering emulsions), which are specialized emulsions distinguished by having a very high volume fraction of the internal phase compared to the external phase. By increasing the interfacial network and preventing dispersed oil droplets from coalescing, stable emulsions are created.[43,44]

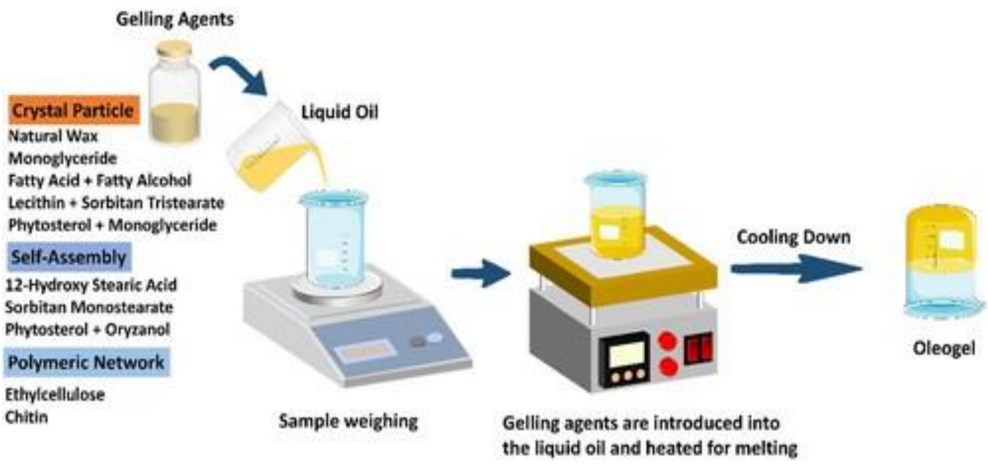
FORMATION OF OLEOGELS

The oleo gels have semisolid properties, the formation of oleo gels are of by two methods; are

1. Direct method
2. Indirect method

Direct Method

Melted oleogelators are dispersed into an oil medium via direct methods of oleogelation, and then cooled to create a self-supporting gel. This method of producing oleogel is known for being straightforward. Oleogelators are first added to the liquid oil, and then chilling is done to start the nucleation process.[45] Crystal growth and the subsequent stability of the crystal lattice are the results of this nucleation. As a result, an oleogel is created, a three-dimensional network that traps the liquid oil phase (Figure 3).(FIG-3).[38]



Numerous gelling agents, mostly divided into three categories—crystal particles, self-assembly, and natural polymers—can be used to accomplish this procedure. Oleogelators are often made of crystal particles like natural waxes, fatty acids/fatty alcohols, phytosterol, and monoglycerides.[46] These substances work similarly to solid fats with a high melting point, forming a structure that limits the flow of liquid oil and gives the finished product a gel-like quality. Nevertheless, these oleogelators produce crystal structures with a shape that differs significantly from that of traditional solid fats. For example, beeswax creates a less thick, fibrous network that results in a semisolid oleogel.[47] This structure is generally softer and more spreadable than traditional solid fats, which are more compact and hard.In this process, the original structural units undergo torsion, helix formation, and one-dimensional growth in the oil phase. All polymer oleogelators, including ethylcellulose and chitin, have demonstrated direct oil structure.[48] A homogenous solution is produced when ethylcellulose is dissolved in an oil medium and heated. Physical entanglements and perhaps some secondary bonding cause the ethylcellulose molecules to combine and form a three-dimensional network structure as they cool. Ethyl-cellulose's ethoxy groups aid in the gelation process and determine how soluble it is in oil. The resultant oleogel usually resembles a network of polymers with many pockets or pores, much like coral. The linear organization of N-acetylglucosamine units results in the formation of chitin, a naturally occurring polymer. When reintroduced into an oil medium, chitin undergoes a breakdown process in particular solvents or under particular conditions, resulting in the creation of a gel network. Through the use of hydrogen bonds and hydrophobic contacts, chitin molecules reassembly into a three-dimensional network is a key component of the gelation mechanism. Processing conditions and the level of chitin deacetylation can affect the structure of chitin-based oleogels.[49]

2. Indirect Method

Indirect method, which usually rely on gelling chemicals that are sensitive to temperature and shear pressures and frequently require relatively high concentrations for successful oleogelation, is the use of indirect methods for oleogel formation.[50] In-direct techniques, such as the use of cheap and plentiful biopolymers, provide a more practical and cost-effective solution. Indirect methods use hydrocolloids or hydrophilic biopolymeric oleogelators as the main oleogel building elements. Using a continuous lipid phase and water exchange, this process creates oleogels. Two popular indirect methods for oil structuring are solvent exchange, which forms a structural framework in a solvent that contains water or in a water-based emulsion and biphasic emulsion (i.e., high internal phase emulsion, foam template and emulsion template. (Figure 4).[51,52,53]

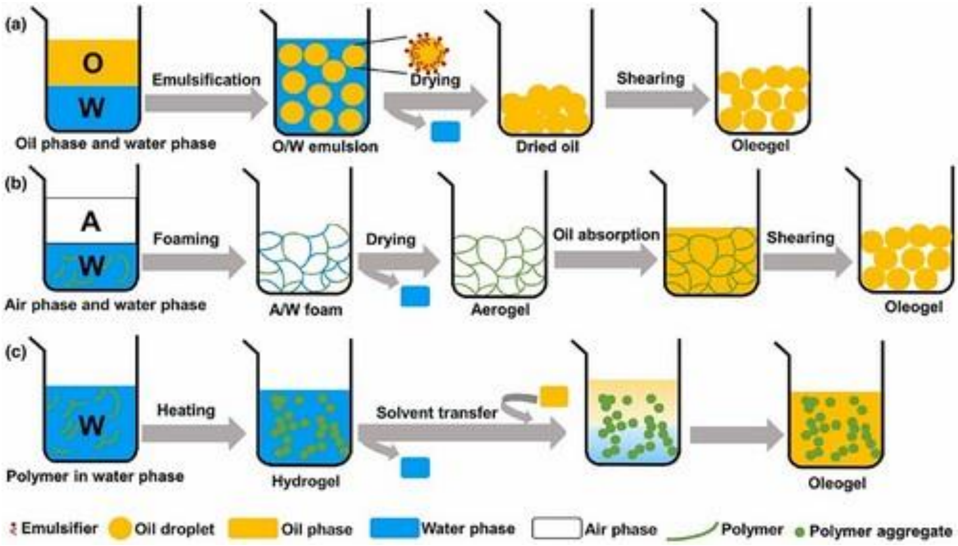


Fig. 4;[43,44,45]

To create a structural framework in this oil-in-water emulsion, surface-active polymers are essential. When the water is subsequently removed by freeze-drying, a gel network is created in which the oil droplets are tightly packed inside the polymer matrix.[53] Shearing pressures are then applied to this network of polymers, resulting in an oleogel with tightly packed oil droplets that are uniformly distributed or clustered as isolated droplets inside the continuous phase and encased in the polymer. However, there are inherent limits to the biphasic emulsion approach when it comes to oleo gel formation. Because of the increased internal pressure caused by the production of tiny crystals before drying, the removal of the aqueous phase during the freeze-drying process of hydrogels may cause the polymer network to collapse internally.[54] The pore collapse issue frequently seen in biphasic emulsion templates can be lessened with the solvent exchange technique. This technique replaces the hydrogels' aqueous phase with acetone or alcohol. To create aerogels, the organic solvents are then eliminated using supercritical carbon dioxide. After that, the oil phase is added to the aerogels' polymeric network via a sequence of dipping or immersion procedures, and the aerogels absorb the oil to form oleogels.[55]

OLEOGELS-PROCESSED MEAT PRODUCTS

Products classified as processed meat include a variety of goods that have changed different processing techniques, such as curing, smoking, and salting, to improve their quality and shelf life.[56] These products' high accessibility and quality (taste, texture, flavor, and nutritional profile) have made them popular in developed nations, and their popularity is steadily growing.[57,58,59,60] Consumer demand for healthy meat products with lower fat and salt content is growing, thus the processed meat industry's ultimate goal is to provide these goods.[61]

The two categories of processed meat products are emulsified (such as frankfurters, sausages, pates, and meat batters) and mixed (such as meatballs, fermented sausages, patties, and burgers) according to the type of processing in question. Mixed meat products don't need to go through the emulsification process like emulsified meat products do. Proteins sustain dispersed lipid droplets in emulsion-type meat products, which are often oil in water.[62] Surface tension and the coalescence forces that cause fat separation are reduced by the amphiphilic character of proteins, which have hydrophilic and hydrophobic sites orientated toward the lipid phase and the aqueous phase, respectively.[63] The key mechanism that gives the emulsion stability is the electrostatic repulsion and steric hindrance that results from the oil droplets. Muscle myofibrillar and sarcoplasmic proteins are frequently seen in meat emulsions due to the superior emulsifying ability of the former and the suppression of myofibrillar protein thermal denaturation by the latter (mostly myoglobin).[64]

The production of stable meat emulsions involves fat, and key factors such as smaller fat globule size for increased stability, cellular structure disintegration for fat release, and a sufficient amount of dissolved protein to coat the surface area of fat droplets (interfacial adsorption) are crucial.[62] About 20% to 30% of processed meat products contain fat, which interacts strongly with the other emulsion ingredients. Because fat gives reformed meat products their tenderness, juiciness, flavor, and physical look, it contributes significantly to the final quality of the meat. An increase in cooking loss and a decrease in hardness was observed when the percentage of fat in the emulsion-based meat products was decreased.[65] In processed meat products, approximately 30% of fat can be added to improve texture and yield. According to reports, goat mortadella's emulsion stability and water-holding capability are enhanced when its fat percentage is raised. This may be because there are more free molecules or radicals interacting with protein or water.[66]

A meat processor's task is to produce a low-fat meat product that is both palatable to consumers and stable in terms of both texture and nutritional value. As the amount of MUFA and PUFA increases and the n-6/n-3 and PUFA/MUFA ratios improve, replacing SFA with liquid oils guarantees that meat products have a rich fatty acid composition. But because liquid oils are highly unsaturated, they oxidize, which is a problem that needs serious attention.[67] Conversely, oleogels have higher oxidative stability than bulk oils because of the oil's entrapment within the gel structure, which significantly reduces oil oxidation.[68] This review focused on replacing animal fat with oleogels in processed meat products because meat batters made with soyabean oil-cellulose-based oleogels demonstrated greater oxidative stability in comparison to control meat batter containing lard/pork back fat. Therefore, proper optimization is necessary for the fabrication of such innovative meat products for them to be successfully marketed and reach the consumer in the best possible way. In this context, it is necessary to identify commercially feasible techniques like reformulation, fat replacers, fat mimetics, or/and a combination of these etc, that have the potential to reduce the fat content of meat products.[69]

APPLICATIONS OF OLEOGELS IN MEAT PRODUCTS

By altering the amounts and lipid composition of processed meat, which are important sources of dietary fat, the nutritional value of the Western diet can be improved.[70] One crucial strategy for creating healthier meat products is reformulation, which involves eliminating, cutting, adding, or swapping out different ingredients. Lowering cholesterol, changing fatty acid profiles, and lowering total fat and energy content are the main goals of fat content improvement by reformulation.[71,72] Although animal fat is frequently substituted with technical means to maximize fatty acid profiles, it might be difficult to preserve the key product attributes (mouthfeel, juiciness, texture, bite, and heat transmission) connected to the solid animal fat in meat products. This is a major technological obstacle when trying to use liquid oils in place of or reduce animal fat.[73] The use of technical methods to replace non-meat fat with animal fat has been extensively studied despite a number of experiments and efforts to increase the fat content of meat products and find alternatives to animal fat. Some previous studies have explored a variety of avenues, such as using different vegetable oils, marine oils, or combinations to partially substitute animal fat in fresh, cooked, and fermented meat products.[74,75] However, there is a dearth of research on using oleogels to create healthier, lipid-rich meat products. More recently, some studies have started looking into the potential applications of oleogel systems in a variety of meat products, including meat burgers, batters, patties and frankfurters, fermented sausages, and pâté, as well as oleogels as a novel approach to produce nutritious meat products.

1. Burgers

Animal fat is essential in burgers because it improves the flavor, texture, and juiciness of the meat. The burger retains its moisture content and flavor throughout cooking thanks to the fat.

Additionally, the fat keeps the beef from crumbling by keeping it together.[79] The flavor of the burger may also be affected by the kind of animal fat used. For example, the unique flavor of beef fat may enhance the meat's flavor. It is important to keep in mind that eating too many animal fats might have negative health effects,[80] thus it is better to eat burgers in moderation as part of a healthy diet. In comparison to the control group, the reformulated burgers showed notable improvements in the fatty acid profile, with the PUFA/SFA ratio increasing by 3.6 times and the n-6/n-3 ratio decreasing by 23 times. When kept at 3 ±1 °C, the oleogels remained stable for at least a month. Beeswax oleogel-made burgers consistently scored highly on sensory acceptability tests, whereas EC-prepared burgers fell short of the neutral rating threshold. In conclusion, the data imply that these oleogels have the potential to make healthier fresh pork burgers with an enhanced fatty acid composition.

Using oleogel, the goal was to create beef burgers with different amounts of animal fat substitution and evaluate their physicochemical characteristics. Using beeswax (BW) at 5%, 7.5%, and 10% concentrations, sesame oil oleogels were created. It was then used to replace 0%, 25%, and 50% of the animal fat in beef patties with oleogel. Different aspects of the formulation and control burger samples were examined in order to evaluate the effect of the inclusion of oleogel. According to the findings, the moisture content rose but the fat content fell as the amount of animal fat replaced by the oleogel increased. The decreased fat content in burgers with a 50% oleogel replacement may be explained by the lower oil absorption during frying that is linked to higher moisture content in food products. Because the fat globules in raw burgers are smaller, the hardness reduced when the amount of animal fat was replaced. When BW oleogel was added, the raw burgers' lightness was greatly decreased.[76] Pork burgers investigated the effects of domestic activities, including as cooking and refrigeration, on the qualitative characteristics of pork patties enhanced with reduced-fat PUFA beyond domestic tasks, they investigated the effects of an oleogelation system that incorporates an antioxidant called curcumin (CU) and a blend of olive, linseed, and fish oil, with an emphasis on the health consequences. Samples constructed with BW, BW-CU, EC, and EC-CU showed higher levels of PUFA and MUFA when compared to a control sample made of pig back fat. The samples that contained oleogel provided roughly twice as many calories as their control counterparts. In contrast to the control, the burgers' softer texture was a result of the use of oleogel. Overall, BW oleogel-infused burgers were judged to have satisfactory sensory qualities and had reduced lipid oxidation during storage.[77]

Ethyl cellulose (EC) oleogel is used in beef burgers in place of some animal fat. EC and sesame oil were combined to create the oleogels, which are necessary for substitution. EC oleogel showed lower levels of palmitic and stearic acids, higher concentrations of linoleic and linolenic acids, and no myristic acid when compared to animal fats. The burger samples' moisture content rose and their fat content fell as the amount of EC oleogel increased. It seems that EC oleogel increased the number of fat globules by interacting with more proteins around them. The saturated fat level of cooked burgers that were substituted with oleogel was approximately double that of control samples that were not substituted with animal fat. However, samples that contained oleogel had decreased oxidative stability. Panelists preferred beef burgers with a higher oleogel content (50%) This study indicates that oleogels may be used to replace animal fat in meat products, improving texture and lowering total fat level.[78]

Table 1: Application of different oleogels in meat -based products and their outcomes.

Meat products	Unsaturated fat	Oleogelator (%)	Gelation conditions	Level of saturated Fat Replacement	Effect of oleogel Incorporation	References
Pork Burgers	Olive, Linseed, and Fish Oil	Ethylcellulose or Beeswax (11%)	160°C or 65° C for 10mins	Pork fat/Partially or 100%	significant enhancement in the PUFA/SFA ratio and a considerable drop of n-6/n-3 ratio. Beeswax oleogel-infused burgers received higher results in the sensory acceptability test.	[75]
Beef burger	Sesame oil	Beeswax (5, 7.5 or 10%)	70°C	Beef fat/0, 25, and 50%	A substantial decrease in the hardness, gumminess, and chewiness of the raw burgers, amounting to less than 50% of the control sample. Increasing oleogel concentration in the burger correlated with a 1.5% reduction in fat absorption.	[76]
Pork Burgers	Olive,Linseed, and Fish Oil	Ethylcellulose or Beeswax (11%)	160°C or 65° C for 10mins	Pork fat100%	The oleogel enhanced the PUFA content with a significant increase in ALA, EPA, and DHA contents, respectively.	[77]

					Beeswax oleogel-incorporated burgers were rated more acceptable.	
Beef burger	Sesame oil	Ethylcellulose (10%)	170^{o}C	Beef fat/0, 25, and 50%	The EC oleogel mitigated the oxidation process during frozen storage and reduced cooking loss and fat absorption in beef burgers. Additionally, the introduction of EC oleogel has led to enhancements in textural properties, specifically in terms of chewiness and hardness.	[78]

2. Sausages and Frankfurters

Ground beef and additional non-meat substances are combined to make sausage, which enhances its flavor, quality, and taste. Traditional sausages have succulent, increased flavor and taste qualities due to their substantial animal fat content.[81] There are several types of sausages, including cured, smoked, and fresh sausages. The most popular kind are the cooked and smoked sausages, often known as frankfurters, franks, wieners, or hot dogs. According to USDA (2016), a typical sausage has roughly 27% fat and 10% saturated fatty acids. Thus, it is clear that replacing fat in a portion of food with such a high fat content is crucial. However, consistency is lost when unsaturated fats are substituted for SFA, resulting in a final product that is unpleasantly soft, has lower sensory acceptability, and is more likely to undergo oxidative degradation. Therefore, it is very difficult to reduce fat in goods made from finely ground meat.[82] It has been observed that using oleogels to partially substitute animal fat in frankfurters improves their nutritional value without sacrificing their structural soundness. Numerous investigations have verified that oleogels tend to improve this processed meat product's technical, functional, and sensory qualities.

That oleogel or emulsion gel, when used in place of hog back fat, produces a more favorable fatty acid profile in the final product. The technical, microbiological, and oxidative stability of sausage were all shown to be identical regardless of the type of animal fat substitute used. Emulsion gel-made fuets, on the other hand, have a hardness comparable to the control, whereas oleogel-prepared ones were softer and shown a lower level of sensory acceptability. When it comes to the commercialization of any reformed product, sensory approval is a crucial criterion. Products must therefore be subjected to sensory analysis by a panel of qualified sensory panelists following formulation. Linseed oil oleogels were used to replace 20 and 40 percent of the pork back fat in reformulated sausages, and their sensory qualities were assessed. Sausage made with oleo gel show less acceptance.[83] The impact of partially substituting olive oil oleogel for pork backfat on the nutritional and technical properties of fermented sausages. Fermented sausage made with 50% oleogels was found to have improved color and texture, being microbiologically safe, and had a 17.8% lower SFA and a more enriched nutritional profile.[84] According to the authors, replacing 50% of meat products with RBOG could increase their softness while lowering their cholesterol and total saturated fat content. Additionally, when compared to other therapies, it demonstrated the best overall acceptance score.[85] Additionally, oleogels have been successful in reducing the amount of residual nitrite in Frankfurt-style cooked sausages. The fatty acid profile was improved and the residual nitrite level was not found in samples that had 75% of the chai oleogel replaced. Since nitrite has been identified as a strong human carcinogen, oleogels have helped to improve the product's safety. Similarly, Table 1 lists other studies that used the oleogel system in place of pork back fat in sausages and found that it can successfully replace animal fat to satisfy consumer demands for low saturated fat and high PUFA without significantly altering the organoleptic qualities of meat products.[86,87]

3. Patties

Research to use sterol-based oleogels in place of animal fat in pig patties.[88] Sterol-based oleogels were made by the researchers using linseed oil and an oryzanol/sitosterol ratio of 60:40 (w/w). These oleogels, which had a structural agent content of 8% (w/w), were used in every experiment. Oleogels are created by combining oryzanol with sitosterol oleogelators, which self-assemble inside the liquid phase. Nevertheless, three sets of patties were made: one set was a control (H-Co), and the other two had sterol-based oleogels used in 25% (H-25) and 75% (H-75) of the subcutaneous swine fat. The patties' physicochemical properties and sensory qualities were examined in detail. Oleogel's contribution, which ranged from 25% to 75% of the overall fat content, affected the samples' hardness. There was a noticeable pattern showing that as the percentage of fat replacement increased, hardness decreased. When sterol-based oleogels are used in place of pork fat, the study showed statistically significant differences in n6/n3 ratios between treatments, which raises the healthier cholesterol fraction in the finished product. To gauge consumer attractiveness, acceptance and preference tests were used in the sensory evaluation. The results showed that customers clearly preferred the control patty samples. Nonetheless, in acceptance and preference tests, the sensory panel gave patties with less oleogel (H-25) positive scores. These findings demonstrated that using oleogels as efficient fat substitutes in patty production is feasible.

Oleogels were created by structurally altering canola oil by adding hydroxypropyl methylcellulose (HPMC). These were then evaluated as a potential substitute for animal fats in the creation of meat patties with less saturated fat.[89] Regardless of temperature changes, these HPMC oleogels displayed solid fat contents and behaved like an elastic gel. Notably, they outperformed canola oil in terms of resistance to oxidative processes, especially when stored in an expedited manner. After using HPMC oleogels at 50% and 100% replacement levels in place of beef tallow in the meat patty formulation, several significant improvements were noted. First off, there was a notable decrease in the patties' cooking loss, which improved moisture retention and product quality overall. Furthermore, the meat patties' texture significantly softened, improving their palatability. Additionally, the nutritional profile was improved by adding HPMC oleogels to the meat patties. In contrast to their beef tallow-based counterparts, which had a significantly higher saturated fat content of 42%, the resulting meat patties incorporating HPMC oleogels had significantly lower amounts of saturated fatty acids, dropping to just 15%. Crucially, these results demonstrate that using HPMC oleogels in place of conventional animal fats not only increases the healthfulness of meat products by lowering their saturated fat content but also preserves their sensory qualities, guaranteeing a delicious eating experience.

4. Meat Batters

According to reports, structured oils change the fatty acid profile of meat batters, particularly by raising PUFA and lowering SFA. Pork back fat in meat batters was completely replaced in a study by[90] using pumpkin seed paste or soy oil oleogels based on ethylcellulose. When compared to control, batter made with oleogel was shown to have a higher PUFA content, lower lipid oxidation, and less calories because of its lower fat content. The control batter and the oleogel-based batter did not significantly vary in terms of textural parameters or consumer approval.[90] A comparison of the effects of employing canola oil in emulsion-type meat batters with hydrogels (containing 1.5% or 3% kappa carrageenan) and ethylcellulose oleogels (containing 0%, 1.5%, or 3% glycerol monostearate) in place of beef fat was carried out.[91] Oleogels made from various oils (sunflower, peanut, corn, and flaxseed oils) and varying ethylcellulose concentrations (8%, 10%, and 12%) were employed in place of pork fat, and their impact on the gel properties of pork batter was examined. Cooked batter based on oleogel exhibited a larger peak area (indicating a higher amount of immobilized water), a shorter relaxation time, increased hardness, gumminess, and chewiness, and improved emulsion stability. Hardness increased as ethylcellulose content rose, while cohesiveness and springiness remained unchanged. According to[92], batters made with pork back fat showed bigger fat globules and a lower L* value than batters made with organogels. However, there was no discernible difference in the two batters' redness (a* values). Fat globules in pig batter employing swine fat were significantly larger than those in batter based on organogels, according to the microstructures of the two types of batter (Fig.5). The beef protein matrix became a consistent, continuous network with smaller fat globules of oleogel batter floating within it. This increased the network's capacity to hold water and bind more soluble chemicals, which reduced cooking loss.

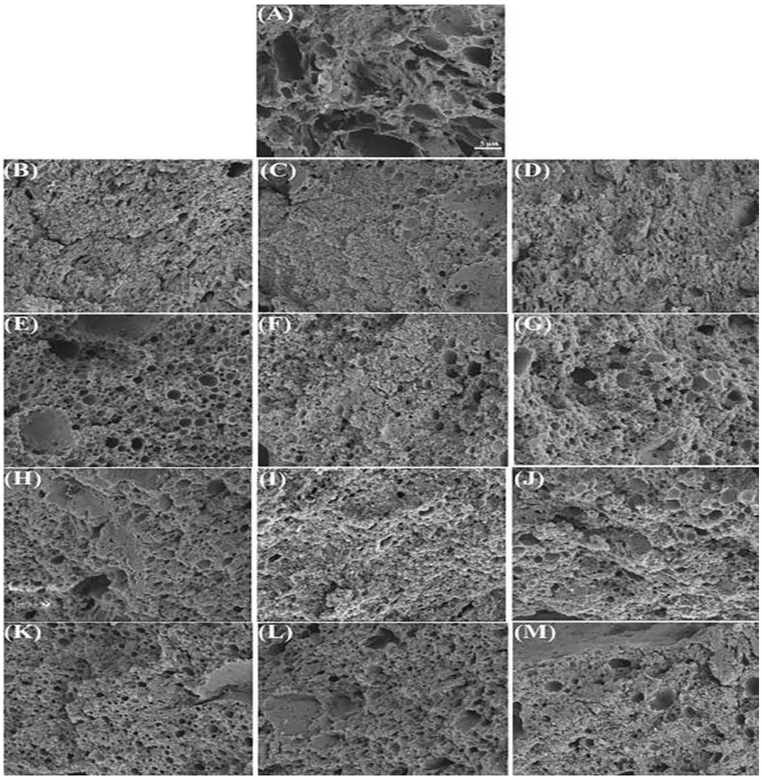


Fig. 5: Micrographs of pork batters prepared with: pork fat (A); sunflower seed oil organogel with 8% EC (B), 10% EC (C) and 12% EC (D); peanut oil organogel with 8% EC (E), 10% EC (F) and 12% EC (G); corn oil organogels with 8% EC (H), 10% EC (I) and 12% EC (J); flaxseed oil organogel with 8% EC (K), 10% EC (L) and 12% EC (M).[92]

5. Pate

Due to its smooth texture and rich flavor, pate, an emulsified spreadable meat product, is well accepted by people worldwide. Lean meat, animal fat, liver, and spices make up the majority of its composition.[93] The kind and quantity of fat in pate, which can range from 17% to 50%, is what gives it its distinct flavor and texture. Unlike other emulsified meat products, pate is prepared differently, incorporating denatured proteins from precooked pork meat. Thus, the function of liver proteins in binding and emulsification becomes crucial. Controlling the temperature between 50 and 55°C is crucial during chopping to guarantee that fat globules are properly emulsified. The key role that fat and liver proteins play in creating a satisfactory final product is highlighted by the absence of functioning lean muscle proteins throughout the emulsification stage.[94]

According to a recent study, using canola oil organogels in place of 60% of the pork fat in pate produced the desired end product with improved textural qualities, improved oil retention over time, and a nearly 40% decrease in SFA. When comparing oleogel-based pate to control and Ṗat´e made entirely of hog fat, no discernible changes in color or sensory qualities were found. Light microscopy showed that when more pork fat was added to the reformulated pate, the size of the fat globules increased somewhat, which ultimately resulted in increased oil losses and less stable batter.[95]

An analysis of the impact of the antioxidant curcumin on the lipid peroxidation of beeswax-based oleogels under accelerated storage conditions revealed that curcumin improved the oleogels' oxidative stability. Strength, oil binding capacity, mechanical, thermal, and rheological characteristics of these oleogels were comparable to those of pork fat at an ideal concentration of 9.12% beeswax and 0.54% curcumin. Lipid oxidation during refrigerated storage is significantly reduced when oleogels are used in place of pork fat in pate, either entirely or partially (Ram et al., 2020). Table 3 lists studies that have been done on using oleogels to substitute fat in pork pate.

OTHER APPLICATIONS

A. Oleogels in the delivery of Nutraceutical

Nutraceuticals are foods or food substances that can prevent or treat disease.[96] Nutraceutical compounds that dissolve in fat include B-carotene, lycopene, curcumin, docosahexaenoic acid (DEA), eicosapentaenoic acid, linoleic acid, linolenic acid, tannins, flavanols, and phytosterols.[97] The therapeutic efficacy of these drugs can be enhanced by using oleogels for controlled release. Because they are a good source of phytosterols and their esters, vegetable fats—which are commonly utilized as the liquid continuous stage in oleogels—are a natural source of nutrients. Incorporating phytosterols into oleogels causes them to erratically travel to an application location with bioactive or therapeutic ingredients. Rats who consumed the phytosterols ceramides and fatty acids from the ceramide group showed improved overall serum lipoprotein composition and a 30% decrease in serum cholesterol.[98,99] Ferulic acid, a nutraceutical component, is also administered orally using a policosanol/olive derived from oil oleogel. Ferulic acid's antioxidant properties make it a promising treatment for diabetes, Alzheimer's disease, cancer, and other degenerative diseases.[100,101]

B. Oleogels in Cosmetics

In contrast to the extensive research on oleogels in food and medicine, cosmetics research is still in its infancy. Vitamins A, D, K, and E, coenzyme Q10, glucosamine, N-acetyl glucosamine, ferulic acid, and other antioxidants are among the lipophilic molecules that make up the majority of the bioactive substances utilized in cosmetics. But instead of using vegetable oils to transport the bioactive compounds, the majority of research focuses on using organic solvents. This could be due to vegetable oils' worse organoleptic properties. Lecithin organogels' liquid continuous medium is a desirable delivery route for cosmetic substances due to its hydrophilic and lipophilic properties.[102] Today's skin care solutions are mostly emulsion-based, meaning they contain both oil and lipid phases. Oils and oleogels are included in this category. Because dermatological cosmetics are especially recommended for skin types that have problems, they are used in these products. The need to find solutions for this population is growing as more people depend on physiological lipids in high dosages, especially those with skin barrier disorders. This is where oleogels, also known as lipogels, are recommended. In contrast to liquid oils, oleogels resemble cream emulsions in that they are semi-solid and gel-like. To achieve this consistency, additives will be used, which give them a sponge-like structure and allow them to absorb massive amounts of lipids.[103] Skin moisture increases more slowly with oleogels than with emulsions. Furthermore, there won't be an external water source like with emulsions. As a result, the only way to stay hydrated is through internal skin processes. The oleogels' lipids aid in this process by reducing trans epidermal water loss (TEWL). Furthermore, naturally occurring water-retaining substances like urea, which has antipruritic qualities, can be added to oleogels. In contrast to emulsions that contain water, there won't be any problems with the urea's long-term stability here.[104]

C. Oleogels in Food Indusrty

In the food industry, oleogels are mostly used to replace unhealthy solid fats. Unsaturated fats, which are thought to be healthier than solid fats, are abundant in these oleogel ingredients.[105] However, their use in the food industry is limited by the scarcity of reasonably priced food-grade oleogels. For example, cookies can be made softer by combining candelilla wax with canola oil.[106] Cakes prepared with shellac oleogels differ significantly from cakes made with shortenings in terms of size, volume, stickiness, and sponginess.[107] Because they may aerate without changing the consistency of the batter, shortenings are frequently chosen. Like conventional shortenings, oleogels can give chocolates thermal stability and foamability. Chocolates use shellac resins as structural agents.[107,108] Therefore, as a healthier substitute for bad solid fats, the use of oleogels in the food business can be investigated. Oleogels provide a better fat alternative because they are high in unsaturated fats.

ADVANTAGES OF MEAT PRODUCTS

Oleogels offer benefits beyond simple fat replacement, making them a strong substitute for animal fats in meat products. Notably, they lessen the need for conventional animal fats by adding liquid vegetable oils, which improve the nutritional value of meat products. Concerns about saturated fats in diets high in unsaturated fatty acids are addressed, encouraging a healthier fat composition in finished goods and satisfying consumer demands for healthier food options. Numerous experimental results support the trend toward using oleogels in meat product formulations. Driven by both nutritional and technological factors, the meat industry can use these findings, which were obtained by researchers in the field, as a foundational reference. Given the widespread health concerns linked to an increase in cardiovascular diseases among consumers, the significance of this shift is highlighted by the recognition that hard fat is a natural reservoir of trans-fats, with processed meat products reportedly containing an average of 35% saturated fats.[109,110] The way oleogels affect the mouthfeel of meat products overall, adding desired textures such as juiciness, smoothness, or creaminess to improve the eating experience.[111] Because it prevents lipid oxidation and textural and sensory degeneration, its structural stability prolongs the shelf life of meat products. After 30 days of storage, Panagiotopoulou et al. (2016) found no statistically significant variations in the levels of lipid oxidation between the control and oleogel-formulated Frankfurter treatments.[112]

FUTURE PROSPECTS OF OLEOGELS

Oleogels have bright futures in the pharmaceutical industry since they provide flexible drug delivery options for a range of situations. Oleogels can solve enduring problems in pharmaceutical formulations as scientists learn more about their characteristics and possible uses. They have the potential to revolutionize the treatment of skin conditions like acne, wound infections, and inflammation because of their capacity to transport medications through the skin. Their capacity to administer medications to the eyes points to a fresh and creative method of treating eye disorders.

Furthermore, the FDA's recent clearance of oleogel-based products highlights the pharmaceutical industry's increasing acceptance of these formulations, opening the door for more developments and creativity in drug delivery methods. Pharmaceutical oleogels therefore have a bright future ahead of them, with chances to improve patient outcomes, treatment accessibility, and therapeutic efficacy.

CONCLUSION

The ability of oleogels to structure edible oils while providing stability, controlled release properties, and improved nutritional profiles makes them valuable in health-conscious product reformulation. Oleogels effectively replace saturated fats in processed meat products with healthier unsaturated alternatives, improving the fatty acid composition without compromising sensory qualities. Their use in drug delivery and cosmetics further highlights their versatility in biomedical and skincare formulations. Oleogels are a promising alternative to traditional fats in a variety of industries, particularly in the food, pharmaceutical, and cosmetics sectors.

The market potential of oleogels is further underscored by the growing consumer desire for healthier substitutes and the backing of regulations aimed at lowering trans and saturated fats. Future studies should concentrate on refining oleogel formulations to improve their functionality, stability, and bioavailability in various applications. Oleogels have a big potential to contribute to the creation of sustainable, wholesome, and efficient substitutes for conventional fats and delivery methods as long as technology keeps improving.

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