Application of Emulsion Gels as Fat Replacement

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Although traditional meat products are highly popular with consumers, the high levels of unsaturated fatty acids and cholesterol present significant health concerns. However, simply using plant oil rich in unsaturated fatty acids to replace animal fat in meat products causes a decline in product quality, such as lower levels of juiciness and hardness. Therefore, it is necessary to develop a fat substitute that can ensure the sensory quality of the product while reducing its fat content. Consequently, using emulsion gels to produce structured oils or introducing functional ingredients has attracted substantial attention for replacing the fat in meat products.

Keywords: emulsion gel ; fat substitute ; healthier meat products ; reduced fat

1. Introduction

Fat-rich meat products are popular with consumers due to their sensory properties. Fat is closely related to several food characteristics, such as texture, taste, and appearance. It also acts as a structuring and tasting agent, supplies energy, serves as a carrier [1][2][3], and directly affects the quality of food consumption and consumer satisfaction. Although traditional meat products are important sources of high-value animal protein [4], the majority of the animal fat is rich in saturated fatty acids (SFA) and cholesterol, and excessive intake increases the incidence of cardiovascular disease, raising the concern for human health [5].

Frankfurters, bologna sausage, beef patties, and other popular meat products typically contain 20–30% fat [6]. The WHO recommends an SFA level of 10% of the total fat intake and that the dietary fat consumption should account for 15% to 30% of the total dietary energy [7]. Although most consumers have the perception of reducing fat and cholesterol intake, which reduces the sales of high-fat foods, it is not feasible to sacrifice the product quality to reduce the fat content of the food [8]. Furthermore, considering global environmental challenges, public health problems, sustainable development, and animal welfare issue [9], while ensuring that the food quality is not lower than the acceptable range for consumers, reducing the amount of animal fat in food and developing fat-free and low-fat food has become an urgent problem to be solved. Fat reduction can be achieved by incorporating fat substitutes in meat products.

Adding fat substitutes to meat products to improve the fatty acid proportions can benefit consumer health. Adding fat substitutes can reduce the fat content in meat products and enhance the distribution of fatty acids. Since the fatty acid composition and proportion significantly impact human health, the polyunsaturated fatty acid (PUFA) to SFA ratio should be between 0.4 and 1.0. Furthermore, because unsaturated fatty acids also have substantial health implications, it is recommended that the n-6/n-3 PUFA ratio not exceed 4. A high n-6/n-3 PUFA ratio can promote the incidence of cardiovascular disease, inflammation, and other disorders. Some meat, such as pork, presents suboptimal fatty acid ratios [7][10].

Using plant oil rich in unsaturated fatty acids to replace animal fat abundant in SFAs is currently attracting significant research attention. However, simply using plant oils to replace animal fats causes a decline in product quality, since animal fats display a solid, elastic structure at room temperature absent in liquid oils. The adipose tissue in meat products consists of liquid oil and solid fat in the connective tissue network, exhibiting both plastic and elastic properties. Animal fat particles play a critical role in the cooking loss rate, hardness, texture, juiciness, flavor, and appearance of meat products [11]. Therefore, liquid plant oil must be treated to resemble animal adipose tissue, reducing the fat content while preserving the original sensory properties of the product as much as possible [12].

Recent studies have focused on utilizing emulsion gels to substitute the animal fat in meat products, forming a network structure via carbohydrate or protein cross-linking, which acted as a matrix for structural fat simulation. Emulsion gel formation is considered a strategy for oil stabilization and structuring, presenting advantages such as transporting functional components and improving the sensory and physical product properties. Since emulsion gels are highly suitable for developing healthy meat products, many studies are currently examining their application prospects.

Emulsion gels with soft, solid textures are more suitable for developing as fat substitutes than traditional emulsions without gel formation. They can better mimic the physical properties of animal fats like pork backfat, such as hardness and water retention capacity. Since these emulsions are more suitable for transporting and protecting oxidized lipids in food[13] and are more successful in preserving flavor substances and bioactive compounds, they can be used to improve the nutritional characteristics of meat products.

A variety of formulations, proteins, polysaccharides, and low-molecular-weight compounds can be used as emulsion gel matrices[14]. These polymer molecules are held together by weak intermolecular forces (e.g., hydrogen bonding, electrostatic forces, Van der Waals forces, and hydrophobic interactions), while covalent bonds (disulfide bonds) are also involved in the heat-induced gelation of globular protein gels[15]. Emulsion gel preparation usually involves the production of a protein-stabilized emulsion, which may also be supplemented with a hydrocolloid stabilizer or other ingredients (proteins, polysaccharides, and surfactants) after emulsion formation[16]. Proteins and polysaccharides are often used as gelation agents in emulsion gels used as fat substitutes, which are broadly classified as protein-, polysaccharide-, and protein–polysaccharide composite-based emulsion gels, depending on the matrix.

2. Protein-Based Emulsion Gels

2.1. The Gelation Mechanism and Influencing Factors

Proteins contain many functional groups that can be covalently cross-linked and are ideal for emulsion gel formation[17].Combining different types of proteins may result in emulsion gels with different properties and expanding their applications in food products[18]. Emulsion-filled protein gels contain proteins that can both stabilize the emulsions as emulsifiers and form network structures as gelation agents[19].The most important concerns during the preparation of protein-based emulsion gels are their rheological properties and network structures, the gelation properties of which are mainly determined by the protein characteristics and concentrations, the oil droplet content, and the heating temperature and time[19], as well as other factors, such as pH, ionic strength, and gelation temperature[20].

The protein-based emulsion gels used in meat products frequently contain soy proteins and sodium caseinate (SC) due to their high nutritional value and emulsification, thickening, and gelation properties[21][22]. Soybean protein provides surfactant molecules, reduces the interfacial tension between oil and water, and enhances the stability of emulsion gels[23]. Studies have shown that soybean protein isolate (SPI) can be employed to produce emulsion gels with excellent freezing-thawing stability and rheological properties using NaCl[24] increasing their potential as fat substitutes. However, compared with polysaccharide and protein–polysaccharide composite-based emulsion gels, it seems more difficult to produce emulsion gels with a certain hardness and gel strength using proteins. Marie-Christin Baune et al.[25] hypothesized that a higher internal phase (oil) content (above 50%) and protein concentration could increase the rigidity and viscoelasticity of emulsion gels. They attempted to identify a commercial separating protein from soy , pea, or potato suitable for preparing pH-neutral (6.5) and heat-resistant (72 ◦C) emulsion gels for use as solid animal fat substitutes. The experiments indicated that both the interfacial and protein–protein interactions of leguminous proteins were involved in structural reinforcement, while the hardness increased with the cysteine content, and the interactions displayed electrostatic, hydrophobic, and hydrophilic properties. Leguminous proteins seem to hold more promise for preparing stable, solid animal fat substitutes suitable for long-term storage than potato proteins.

2.2. Protein-Based Emulsion Gels as Fat Substitutes in Meat Products

(1)Reducing the fat content and improving the fatty acid profile

Several studies have examined the addition of protein-based emulsion gels to meat products as fat substitutes. Pintado et al.[26]used olive oil and chia oil as raw materials to structurally prepare oleogels, while SPI and gelation agents (gelatin) were added to prepare emulsion gels. Oleogels are a type of organogels, which can be defined as a three-dimensional cooling network structure with thermally reversible properties formed by an organic liquid and organogelators. When the organic phase of an organogel is edible oil, it is called an oleogel. Unlike emulsion gels, which are formed by making the continuous phase gelation, oleogels are liquid oils that are transformed to a gel state by organogelators, such as beeswax, which consist mainly of oil and have a much higher oil content than emulsion gels[27][28]. In this study , both gels were used as fat substitutes, and their suitability for replacing functional fermented meat product (fuet) was evaluated. The results indicated that fat substitution improved the fatty acid composition of the products, with a 12-fold decrease in the unsaturated fatty acid n-6/n-3 ratio compared to the control samples with normal fat content and reduced fat content (more water), while the products exhibited an excellent oxidative and microbial status during a 30-d frozen storage period. Therefore, both the emulsion gel and oleogel could be used as meat product fat substitutes.

Various studies have explored the gelation mechanism of protein-based emulsion gels and new gel preparation methods to obtain fat substitutes with physical, chemical, and sensory properties similar to real animal fats. Dreher et al.[11] suggested that a certain amount of solid fat could increase the similarity of the key properties of fat mimetics derived from plant materials to animal adipose tissue. Melted solid-state hydrogenated canola oil was mixed with liquid canola oil and added to a solution containing an excess of hot emulsified SPI, which was covalently cross-linked using TG to produce a protein network. The internal solid fat was allowed to crystallize to form additional networks, ultimately resulting in an integral emulsion gel with melting and elastic properties. The results indicated that the emulsification of a lipid crystal network consisting of liquid plant oil and solid plant-derived fat with excess plant proteins produced different structures via TG-induced cross-linking. Furthermore, plant-derived lipids could be engineered to create fat crystal networks that mimic the mechanical properties of animal fats via sequential melting, emulsification, cooling, and cross-linking.

In addition, several studies[12][29][30][31]explored the effect of the protein content on plant-based emulsified cross-linked fat crystal networks simulating animal adipose tissue, confirming that the textural and rheological properties of emulsion gels can be changed to some extent by modifying the protein content in the initial emulsion before TG cross-linking.

(2) Structured liquid oils

Plant or marine oils rich in unsaturated fatty acids are primarily in a liquid state. The introduction of these liquid oils with completely different physicochemical properties from solid animal fats can negatively affect the quality of the product. Liquid oils can be modified or structured to present a healthy fatty acid composition while maintaining their solid characteristics and plasticity[32].Emulsion gels can be used for liquid oil structuring, providing a strategy for introducing healthier oils into reformulated low-fat meat products. Since liquid oils are stabilized in a gel network composed of a protein matrix, the O/W emulsion gel containing non-meat proteins improves the fat binding capacity of the system, stabilizing the oil in the structures of the meat products. Several studies[33][34][35]introduced healthy oil combinations consisting of olive, linseed, and fish oil, into Frankfurters, using different protein-stabilized O/W emulsions. Furthermore, TG enzymes were incorporated to facilitate gel structure formation, yielding low-fat meat products with low SFA and high PUFA levels and suitable n-6/n-3 ratios that displayed consumer acceptability , indicating that this was a feasible method for stabilizing liquid oils.

(3)The introduction of functional ingredients and application of new technologies

Compared with emulsions, oleogels, and hydrogels[36], emulsion gels are a better choice for improving the nutritional properties of food by carrying hydrophobic compounds and functional ingredients and protect bioactive compounds that act as carriers for hydrophobic compounds and functional ingredients and protect bioactive compounds within them [37]. Compounds, such as polyphenols, display antioxidant activity and are often artificially added to improve the nutritional properties of foods. However, directly adding polyphenols to meat products degrades or inactivates them and may also cause a decline in the quality of the color and taste.

Freire et al.[38] formulated emulsions using different protein emulsifiers and a lipid phase rich in n-3 unsaturated fatty acids. They produced cold-set gels after adding a natural extract rich in concentrated tannins (CT), increasing the antioxidant activity and stability . Pintado et al. [39] used extra virgin olive oil and SPI to produce emulsion gels as a phenolic compound delivery system to provide the product with moderate amounts of polyphenols to take advantage of their health benefits. Therefore, the use of emulsion gels containing two different polyphenol extracts (grapeseed or grapeseed and olive) as fat substitutes in Frankfurters was evaluated. The results indicated that incorporating the emulsion gel reduced the SFA proportion in the product by half with a higher PUFA/SFA ratio. Moreover, the Frankfurters containing the emulsion gel with the solid polyphenol extract displayed high levels of hydroxytyrosol (Hxt) and gallic acid, flavanol monomers, and their derivatives, while the trophic advantage did not cause undesirable sensory or structural changes and provided excellent stability . Therefore, the emulsion gel is suitable as a release system for polyphenols without obviously influencing the sensory properties of the product.

Shahbazi et al.[40][41] used SPI and canola oil as raw materials to prepare emulsions. Several different biosurfactant agents (ethyl cellulose (EHEC), octenyl succinic anhydride (OSA) starch, acetylated starch, and dodecyl succinate (DS) inulin) were separately added to the emulsion to replace some or all of the oil to prepare the desired low-fat soy protein emulsion gel, which was applied for 3D printing. Consequently , the emulsion gel was suitable for ink development when 3D printing low-fat artificial meat, providing a method for developing 3D-printed plant-based meat products.

3. Polysaccharide-Based Emulsion Gel

3.1. Gelation Mechanism and Influencing Factors

When preparing emulsion gels as fat substitutes, it is necessary to maintain the desired appearance and rheological characteristics and acceptable sensory properties of the meat products after gel incorporation. An increase in the fat substitute proportion is generally associated with a decrease in sensory quality , especially a deterioration in juiciness, while polysaccharide gels display a higher water-retention ability and are suitable for constructing gels with different properties. Lipophilic agents with beneficial health effects can be incorporated into food while maintaining the product characteristics[13].

During the preparation process of polysaccharide-based emulsion gel, the polysaccharides are dissolved at a high temperature, the emulsions are prepared at a moderate temperature, and gels are formed at a low temperature. The gelation mechanisms include the formation of double and cross-linked helical domains during cooling to form 3D structures[14].The advantages of polysaccharides include their ability to control food texture and flavor release[15], while their diverse structures and gelation conditions show significant promise for tailoring gels with desirable structures[42].Characteristics such as molecular weight, size, monosaccharide composition, charge density , molecular conformation, and extrinsic conditions, such as temperature, pH, and ionic strength, are important factors affecting the structures of polysaccharide gels. Polysaccharides such as agar, carrageenan, pectin and konjac, are also important gelling agents in food, and they can also be considered as gel matrices [28].Polysaccharides can form gels at concentrations below 1% via various molecular interactions [43].

3.2. Polysaccharide-Based Emulsion Gels as Fat Substitutes in Meat Products

Inulin and chia powder are often used as raw materials for polysaccharide-based emulsion gels due to their rich dietary fiber and functional properties, such as gelling, emulsification, and fat water-binding abilities[44][45]. In addition to its gelation, thickening, and stability properties[46], carrageenan can also act as a meat binder and a texture stabilizer[21]. Some studies indicated that adding dietary fiber to meat products can help improve the stability and rheological properties of emulsions[47].Many polysaccharide biopolymers, such as konjac, inulin, and carrageenan, are commonly used to develop fat substitutes and have yielded excellent results thus far. Konjac glucomannan, extracted from the east Asian native plant, konjac, can be used for gel formation and fat substitution. Konjac gels can be ground to the desired particle size to simulate visible granular fat, which is suitable for mimicking the sensory properties and replacing animal fat[48].

(1)Reducing the fat content and improving the fatty acid profile

Using polysaccharide emulsion gels as fat replacers can improve the water retention of meat products and promote regular water release during fermentation, which can maintain the sensory properties of products, such as dried fermented sausages[49]. Alejandre et al.[50]prepared high-ω-3-content emulsion gels using κ-carrageenan and linseed oil. The phases were heated separately to 70 ◦C and emulsified via homogenization. Emulsion gel formation occurred via κ-carrageenan polymerization after gel cooling, allowing its application in dry-fermented sausages as a fat replacement. Compared with the control group, this method improved the fatty acid composition of dry-fermented sausages, reducing the ω-6/ω-3 ratio. The addition of this emulsion gel increased the α-linolenic and ω-3 unsaturated fatty acid content, while no significant differences were evident in the color, taste, and juiciness of the reformulated low-fat sausages compared to traditional dry-fermented sausages. Therefore, emulsion gels prepared using linseed oil and carrageenan can be used as an alternative to dry-fermented sausages, since they retain sensory qualities acceptable to consumers.

(2)Structured liquid oils

Even though not prepared as an emulsion gel, gels produced using only polysaccharides can also be used as fat replacers. Although Ruiz-Capillas et al. [48] effectively reduced the fat in dry-fermented sausages using konjac gel as a fat substitute, this technique decreased the quality of the products to some extent. However, since the properties of emulsion gels differ from standard polysaccharide gels, liquid plant oils can be introduced into meat systems. Adding healthier plant oils may improve the fatty acid profiles in meat products while reducing the fat content. However, healthy plant oil rich in unsaturated fatty acids is prone to accelerated oxidative deterioration and shorter shelf life of foods while reducing the plasticity of the final product, causing a textural decrease and loss of nutritional properties. Therefore, it is necessary to stabilize the emulsion by reinforcing the structure. Structured liquid oil converted into emulsion gels can produce rheological properties close to those of animal fat [23][50], showing promise as a fat replacement approach when designing and developing low-fat meat products. Alejandre et al. [27] compared an organogel and an emulsion gel with κ-carrageenan as a matrix to examine the effect of animal fat replacement in these two structured oil systems in meat batter. The results indicated that meat batters formulated using organogels exhibited higher matrix stability and were incorporated into the meat matrix more efficiently than meat batter formulated with emulsion gels. However, the emulsion gel showed sufficient performance as a structured oil method, compensating for the deficiencies of direct plant oil addition. Therefore, it could be used as a fat substitute in the meat batter. Many studies have mixed olive oil, linseed oil, and other healthy oils to create stable emulsion gels with polysaccharide matrices, which were added to Frankfurters and other meat products to replace the fat, achieving relatively favorable results [51][52][53][54].

(3)The development of fat cube substitutes

Polysaccharide-based emulsion gels can be converted into cubes to provide the appearance of visible fat lumps in meat products [55], such as sausages, consisting of a mixture of solid lumps of pork backfat and lean meat. However, studies involving simulated solid fat cubes and emulsion gels indicated that the emulsion gel must display a certain hardness and strength. Chen et al. [49] prepared fat cube substitutes using konjac glucomannan and κ -carrageenan to partially replace the pork backfat in dry Harbin sausages. The results showed that although using solid cube fat substitutes prepared via an emulsion gel was a feasible method for reducing the fat content in dry-fermented Harbin sausages, the property changes were related to the substitution level. No significant differences were evident between the physicochemical and sensory properties of the lower substitution level group and the control group, while high substitution levels produced changes in product characteristics. To ensure the sensory attributes of the dry Harbin sausages, the upper limit of the cube fat substitution level was 40%.

(4)The introduction of functional components

As with their protein-based counterpart, polysaccharide-based emulsion gels can also be used to protect active substances and improve the nutritional value of food products. Alejandre et al. [56] added catechin-rich natural extracts from blackthorn branches to a κ-carrageenan emulsion gel system containing microalgal oil to obtain functional ingredients and use it as a fat substitute in beef patties. The results indicated that adding the extract to the polysaccharide-based emulsion gel system did not affect the overall sensory properties and acceptability of the product. Moreover, the extract provided high antioxidant properties to the emulsion gel, decreased the fat content in the beef patties after fat substitution, doubled the antioxidant activity and DHA content, and increased the antioxidant stability by reducing peroxide content.

4. Protein–Polysaccharide Composite-Based Emulsion Gels

4.1. The Gelation Mechanism and Influencing Factors

Combining proteins and polysaccharides represents a new approach for developing novel solid fat mimetics. Compared with the other two matrices, the composite matrix has been studied more extensively and presents a broader application scope. Emulsion gels containing polysaccharides and proteins display a higher similarity to real gel systems in food [28]. The simultaneous addition of protein and polysaccharide macromolecules may cause intermolecular correlations via electrostatic interaction, complex coacervation, and associative phase separation [57] to generate complexes that can quickly form network structures in food systems and produce diverse functions [58]. This method is commonly used to control the structure of food products for better texture and stability, while the diverse structures and gel conditions of polysaccharides make it possible to tailor gels with desirable structures [42].

Protein–polysaccharide gels are produced via gelation that does not require a denaturing process during protein gel preparation. The porosity and structures of the gels can be adjusted by changing conditions, such as protein or polysaccharide species, added quantity, ratio, pH, and salt concentration, while potentially altering the rheological properties and stabilizing the emulsions [43]. After a protein-based emulsion gel is generated, the hydrocolloids and other natural ingredients formed by the polysaccharides can also be added to tailor the gel structure and functionality. Furthermore, adding flaxseed gum changes the rheological properties of peanut protein isolate emulsions and gels, acts as a thickener to reduce gelation time, and improves gel strength [58]. Flaxseed gum or flax gum addition also enhances the apparent viscosity of SPI emulsion [59], playing a crucial role in improving the emulsion gelation properties, enhancing thermal stability, and increasing the structural strength of the gel network [60]. Therefore, adding polysaccharides to the aqueous phase of emulsions can act as a thickener, improving emulsion instability.

4.2. Protein–Polysaccharide Composite-Based Emulsion Gels as Fat Substitutes in Meat Products

(1)Reducing the fat content and improving the fatty acid profile

Protein–polysaccharide composites display better functionality than individually acting proteins or polysaccharides. Santos et al. [61] used pork skin, inulin, α-cyclodextrin, and bamboo fiber as raw materials to replace the pork backfat in emulsified meat products. The pork skin, rich in collagen, exhibited high gelation and emulsification capacity. Furthermore, the interaction between the pork skin and dietary fiber significantly improved the hardness and stability of the emulsion gel, while the addition of bamboo fiber also enhanced the performance of the emulsion gel to a certain extent. The application scope of composite-based emulsion gels is broader than those with a single matrix. They are used in meat products, such as sausages and burger patties, as well as for developing seafood analogs. Modifying their concentrations can control the texture and network structures of the gels. Ran et al. [62] used konjac glucomannan to enhance cross-linking with soy protein to mimic the texture of fish balls. According to the results, konjac glucomannan addition significantly affected the textural and rheological properties of plant-based fish balls while increasing the hardness, chewiness, and gel strength at a higher concentration. The addition of konjac glucomannan contributes to the formation of a tighter gel network and denser cross-linking. A low konjac concentration increases the porosity and density of the structure, while an appropriate concentration enhances elasticity and gel strength. Therefore, the polysaccharide–protein composite-based emulsion gel displays excellent potential and application value for developing plant-based seafood analogs and novel low-fat meat products.

(2)The development of fat cube substitutes

Both the strength and hardness of the gels can be improved by the combined effect of polysaccharides and proteins. This change is beneficial to the formation of the 3D cube fat substitute, modifying the textural properties and gel network structures of emulsion gels by adjusting the number of added polysaccharides and proteins, facilitating customization to obtain the optimal emulsion gel structure. Huang et al. [31]used an aqueous SPI solution homogenized with coconut oil to prepare an emulsion and subsequently added konjac glucomannan to obtain a 3D cube emulsion gel with a certain hardness and strength via the TG cross-linking effect. This was used as a fat substitute to study the effect of adding different protein and konjac concentrations to the emulsion gel systems. The findings indicated that the emulsion gel could be used to simulate a solid cube fat. It was similar to pork fat in appearance, exhibited desirable functional qualities in terms of both mechanical and oral tribological properties, and was favored by consumers at an added protein content of 1% and konjac content of 4%. The 3D structures of fat substitutes can provide the product with the desired visible fat cube appearance, for which a protein–polysaccharide composite matrix offers a potential approach. Moreover, protein–polysaccharide complexes are more successful in improving the performance deficit caused by a single raw material matrix than proteins or polysaccharides alone.

(3)The application of cereal flour as a composite matrix emulsion gel

In addition to dietary fiber and protein, some cereal powder products also contain a high number of bioactive compounds, such as cocoa bean shells rich in catechins, theobromine, and caffeine, which can be used as matrices for developing emulsion gels[63]. Pintado et al. [64]used emulsion gels as delivery systems for healthier bioactive plant compounds to prepare gels from chia powder and olive oil as fat substitutes in low-fat Frankfurters. The results showed that adding chia powder emulsion gel reduced the fat level to 40%, consequently decreasing the energy intake by 30%, which could be labeled as “reduced fat content”. The reformulated Frankfurter contained a large number of minerals, such as magnesium, manganese, and calcium, with more lipid–protein interactions. Adding the emulsion gel retained the sensory characteristics of the Frankfurters within the accepted range, while the product displayed oxidative stability during storage. Subsequent studies used chia and oat-based emulsion gels to replace animal fats in low-fat fresh sausages (longanizas) [65][66]. This reduced the product fat and energy, improved the fatty acid ratio, decreased cooking loss, and increased the concentrations of certain minerals and amino acids. In addition, oat emulsion gels are used as fat substitutes to provide meat products with β-glucan and monounsaturated fatty acids (MUFA)[67]. Therefore, chia or oat emulsion gels as animal fat substitutes may increase the nutritional value of meat products, such as Frankfurters.

(4)Changes in the sensory properties of products caused by different substitution ratios

Due to the role of fat in meat products, changes in the sensory properties limit the application of fat substitutes. Therefore, meat products with an appropriate proportion of emulsion gel yielded mostly desirable results in sensory evaluation tests, while 100% animal fat substitution usually produced various negative effects. Serdaroglu et al.[68] showed that completely replacing the beef fat in chicken patties with emulsion gels produced the lowest sensory evaluation scores, while samples with 25% and 50% fat substitution exhibited similar scores to the whole fat samples. The results indicated that adding 50% emulsion gel rendered the chicken patties similar to the original product. The beef fat played an important role in flavor and provided the product with its characteristic flavor, even when reduced by half. Studies have shown that replacing all the fat with emulsion gels negatively impacts meat products[64][69]. In most studies, the meat products in which 50% of the fat was replaced by emulsion gel displayed the best comprehensive quality, while a total substitution decreased the sensory properties of the samples while negatively affecting the textural and technological performance[70]. However, Berker Nacak et al.[71]produced composite emulsion gels using peanut and linseed oil to replace beef fat. These samples showed higher oil scores and overall acceptability during the sensory evaluation than the whole-fat control specimens. This result could be attributed to the emulsion gel providing the desired taste by covering the oil beads and their characteristic solid-like structures, consequently displaying a high simulation capacity. The different results may be related to the selection of raw materials, preparation technology, and the application of emulsion gels in different meat products. However, emulsion gels can potentially reduce the fat content of meat products and improve the distribution of fatty acids without reducing the sensory quality.

References

1. Siri-Tarino, P.W.; Chiu, S.; Bergeron, N.; Krauss, R.M. Saturated Fats Versus Polyunsaturated Fats Versus Carbohydrates for Cardiovascular Disease Prevention and Treatment. Annu. Rev. Nutr. 2015, 35, 517–543.
2. Calder, P.C. Functional Roles of Fatty Acids and Their Effects on Human Health. J. Parenter. Enter. Nutr. 2015, 39, 18S–32S.
3. Geremias-Andrade, I.M.; Souki, N.; Moraes, I.C.F.; Pinho, S.C. Rheological and mechanical characterization of curcumin-loaded emulsion-filled gels produced with whey protein isolate and xanthan gum. LWT-Food Sci. Technol. 2017, 86, 166–173.
4. Valsta, L.M.; Tapanainen, H.; Mannisto, S. Meat fats in nutrition. Meat Sci. 2005, 70, 525–530.
5. Houston, D.K.; Ding, J.; Lee, J.S.; Garcia, M.; Kanaya, A.M.; Tylavsky, F.A.; Newman, A.B.; Visser, M.; Kritchevsky, S.B.; Hlth, A.B.C.S. Dietary fat and cholesterol and risk of cardiovascular disease in older adults: The Health ABC Study. Nutr. Metab. Carbiovasc. Dis. 2011, 21, 430–437.
6. Colmenero, F.J. Relevant factors in strategies for fat reduction in meat products. Trends Food Sci. Technol. 2000, 11, 56–66.
7. Jimenez-Colmenero, F. Healthier lipid formulation approaches in meat-based functional foods. Technological options for replacement of meat fats by non-meat fats. Trends Food Sci. Technol. 2007, 18, 567–578.
8. Bishop, D.J.; Olson, D.G.; Knipe, C.L. Pre-emulsified corn oil, pork fat, or added moisture affect quality of reduced fat bologna quality. J. Food Sci. 1993, 58, 484–487.
9. Lang, Z.; Yingying, H.; Hussain Badar, I.; Xiufang, X.; Baohua, K.; Qian, C. Prospects of artificial meat: Opportunities and challenges around consumer acceptance. Trends Food Sci. Technol. 2021, 116, 434–444.
10. Wood, J.D.; Richardson, R.I.; Nute, G.R.; Fisher, A.V.; Campo, M.M.; Kasapidou, E.; Sheard, P.R.; Enser, M. Effects of fatty acids on meat quality: A review. Meat Sci. 2004, 66, 21–32.
11. Dreher, J.; Blach, C.; Terjung, N.; Gibis, M.; Weiss, J. Formation and characterization of plant-based emulsified and crosslinked fat crystal networks to mimic animal fat tissue. J. Food Sci. 2020, 85, 421–431.
12. Dreher, J.; Weissmuller, M.; Herrmann, K.; Terjung, N.; Gibis, M.; Weiss, J. Influence of protein and solid fat content on mechanical properties and comminution behavior of structured plant-based lipids. Food Res. Int. 2021, 145, 110416.
13. Poyato, C.; Astiasaran, I.; Barriuso, B.; Ansorena, D. A new polyunsaturated gelled emulsion as replacer of pork back-fat in burger patties: Effect on lipid composition, oxidative stability and sensory acceptability. LWT-Food Sci. Technol. 2015, 62, 1069–1075.
14. Lin, D.Q.; Kelly, A.L.; Miao, S. Preparation, structure-property relationships and applications of different emulsion gels: Bulk emulsion gels, emulsion gel particles, and fluid emulsion gels. Trends Food Sci. Technol. 2020, 102, 123–137.
15. Banerjee, S.; Bhattacharya, S. Food Gels: Gelling Process and New Applications. Crit. Rev. Food Sci. Nutr. 2012, 52, 334–346.
16. Herrero, A.M.; Ruiz-Capillas, C.; Pintado, T.; Carmona, P.; Jimenez-Colmenero, F. Infrared spectroscopy used to determine effects of chia and olive oil incorporation strategies on lipid structure of reduced-fat frankfurters. Food Chem. 2017, 221, 1333–1339.
17. Tang, C.H.; Chen, L.; Foegeding, E. Mechanical and Water-Holding Properties and Microstructures of Soy Protein Isolate Emulsion Gels Induced by CaCl2, Glucono-δ-lactone (GDL), and Transglutaminase: Influence of Thermal Treatments before and/or after Emulsification. J. Agric. Food Chem. 2011, 59, 4071–4077.
18. Yuqing, Z.; Xing, C.; McClements, D.J.; Liqiang, Z.; Wei, L. pH-, ion- and temperature-dependent emulsion gels: Fabricated by addition of whey protein to gliadin-nanoparticle coated lipid droplets. Food Hydrocoll. 2018, 77, 870–878.

19. Mao, L.K.; Roos, Y.H.; Miao, S. Study on the Rheological Properties and Volatile Release of Cold-Set Emulsion-Filled Protein Gels. J. Agric. Food Chem. 2014, 62, 11420–11428.

20. Aiqian, Y.; Taylor, S. Characterization of cold-set gels produced from heated emulsions stabilized by whey protein. Int. Dairy J. 2009, 19, 721–727.

21. Paglarini, C.D.S.; Furtado, G.D.F.; Biachi, J.P.; Silva Vidal, V.A.; Martini, S.; Soares Forte, M.B.; Cunha, R.L.; Rodrigues Pollonio, M.A. Functional emulsion gels with potential application in meat products. J. Food Eng. 2018, 222, 29–37.

22. Perr Ec Hil, F.A.; Cunha, R.L. Stabilization of multilayered emulsions by sodium caseinate and κ-carrageenan. Food Hydrocoll. 2013, 30, 606–613.

23. Paglarini, C.D.; Furtado, G.D.; Honorio, A.R.; Mokarze, L.; Vidal, V.A.D.; Ribeiro, A.P.B.; Cunha, R.L.; Pollonio, M.A.R. Functional emulsion gels as pork back fat replacers in Bologna sausage. Food Struct. 2019, 20, 100105.

24. Jie, Y.; Yong, W.; Dong, L.; Li-jun, W. Freeze-thaw stability and rheological properties of soy protein isolate emulsion gels induced by NaCl. Food Hydrocoll. 2022, 123, 107113.

25. Baune, M.C.; Schroeder, S.; Witte, F.; Heinz, V.; Terjung, N. Analysis of protein-network formation of different vegetable proteins during emulsification to produce solid fat substitutes. J. Food Meas. Charact. 2021, 15, 2399–2416.

26. Pintado, T.; Cofrades, S. Quality Characteristics of Healthy Dry Fermented Sausages Formulated with a Mixture of Olive and Chia Oil Structured in Oleogel or Emulsion Gel as Animal Fat Replacer. Foods 2020, 9, 830.

27. Alejandre, M.; Astiasaran, I.; Ansorena, D.; Barbut, S. Using canola oil hydrogels and organogels to reduce saturated animal fat in meat batters. Food Res. Int. 2019, 122, 129–136.

28. Herrero, A.M.; Ruiz-Capillas, C. Novel lipid materials based on gelling procedures as fat analogues in the development of healthier meat products. Curr. Opin. Food Sci. 2021, 39, 1–6.

29. Dreher, J.; Blach, C.; Terjung, N.; Gibis, M.; Weiss, J. Influence of Protein Content on Plant-Based Emulsified and Crosslinked Fat Crystal Networks to Mimic Animal Fat Tissue. Food Hydrocoll. 2020, 106, 105864.

30. Herz, E.; Herz, L.; Dreher, J.; Gibis, M.; Ray, J.; Pibarot, P.; Schmitt, C.; Weiss, J. Influencing factors on the ability to assemble a complex meat analogue using a soy-protein-binder. Innov. Food Sci. Emerg. Technol. 2021, 73, 102806.

31. Huang, L.; Ren, Y.; Li, H.; Zhang, Q.; Wang, Y.; Cao, J.; Liu, X. Create Fat Substitute From Soybean Protein Isolate/Konjac Glucomannan: The Impact of the Protein and Polysaccharide Concentrations Formulations. Front. Nutr. 2022, 9, 843832.

32. Jimenez-Colmenero, F.; Salcedo-Sandoval, L.; Bou, R.; Cofrades, S.; Herrero, A.M.; Ruiz-Capillas, C. Novel applications of oil-structuring methods as a strategy to improve the fat content of meat products. Trends Food Sci. Technol. 2015, 44, 177–188.

33. Delgado-Pando, G.; Cofrades, S.; Ruiz-Capillas, C.; Solas, M.T.; Triki, M.; Jimenez-Colmenero, F. Low-fat frankfurters formulated with a healthier lipid combination as functional ingredient: Microstructure, lipid oxidation, nitrite content, microbiological changes and biogenic amine formation. Meat Sci. 2011, 89, 65–71.

34. Delgado-Pando, G.; Cofrades, S.; Ruiz-Capillas, C.; Jimenez-Colmenero, F. Healthier lipid combination as functional ingredient influencing sensory and technological properties of low-fat frankfurters. Eur. J. Lipid Sci. Technol. 2010, 112, 859–870.

35. Delgado-Pando, G.; Cofrades, S.; Ruiz-Capillas, C.; Solas, M.T.; Jiménez-Colmenero, F. Healthier lipid combination oil-in-water emulsions prepared with various protein systems: An approach for development of functional meat products. Eur. J. Lipid Sci. Technol. 2010, 112, 791–801.

36. Farjami, T.; Madadlou, A. An overview on preparation of emulsion-filled gels and emulsion particulate gels. Trends Food Sci. Technol. 2019, 86, 85–94.

37. Paglarini, C.d.S.; Martini, S.; Pollonio, M.A.R. Using emulsion gels made with sonicated soy protein isolate dispersions to replace fat in frankfurters. LWT-Food Sci. Technol. 2019, 99, 453–459.

38. Freire, M.; Cofrades, S.; Perez-Jimenez, J.; Gomez-Estaca, J.; Jimenez-Colmenero, F.; Bou, R. Emulsion gels containing n-3 fatty acids and condensed tannins designed as functional fat replacers. Food Res. Int. 2018, 113, 465–473.

39. Pintado, T.; Munoz-Gonzalez, I.; Salvador, M.; Ruiz-Capillas, C.; Herrero, A.M. Phenolic compounds in emulsion gel-based delivery systems applied as animal fat replacers in frankfurters: Physico-chemical, structural and microbiological approach. Food Chem. 2021, 340, 128095.

40. Shahbazi, M.; Jager, H.; Chen, J.S.; Ettelaie, R. Construction of 3D printed reduced-fat meat analogue by emulsion gels. Part II: Printing performance, thermal, tribological, and dynamic sensory characterization of printed objects. Food

Hydrocoll. 2021, 121, 107054.

41. Shahbazi, M.; Jager, H.; Ettelaie, R.; Chen, J.S. Construction of 3D printed reduced-fat meat analogue by emulsion gels. Part I: Flow behavior, thixotropic feature, and network structure of soy protein-based inks. Food Hydrocoll. 2021, 120, 106967.
42. van den Berg, L.; Rosenberg, Y.; van Boekel, M.; Rosenberg, M.; van de Velde, F. Microstructural features of composite whey protein/polysaccharide gels characterized at different length scales. Food Hydrocoll. 2009, 23, 1288–1298.
43. Le, X.T.; Rioux, L.E.; Turgeon, S.L. Formation and functional properties of protein-polysaccharide electrostatic hydrogels in comparison to protein or polysaccharide hydrogels. Adv. Colloid Interface Sci. 2017, 239, 127–135.
44. Yousefi, M.; Khorshidian, N.; Hosseini, H. An overview of the functionality of inulin in meat and poultry products. Nutr. Food Sci. 2018, 48, 819–835.
45. Coorey, R.; Tjoe, A.; Jayasena, V. Gelling Properties of Chia Seed and Flour. J. Food Sci. 2014, 79, E859–E866.
46. Gao, X.-Q.; Kang, Z.-L.; Zhang, W.G.; Li, Y.P.; Zhou, G.-H. Combination of κ-Carrageenan and Soy Protein Isolate Effects on Functional Properties of Chopped Low-Fat Pork Batters During Heat-Induced Gelation. Food Bioprocess Technol. 2015, 8, 1524–1531.
47. Botella-Martínez, C.; Fernández-López, J.; Pérez-Lvarez, J.; Viuda-Martos, M. Gelled Emulsions Based on Amaranth Flour with Hemp and Sesame Oils. Proceedings 2021, 70, 98.
48. Ruiz-Capillas, C.; Triki, M.; Herrero, A.M.; Rodriguez-Salas, L.; Jimenez-Colmenero, F. Konjac gel as pork backfat replacer in dry fermented sausages: Processing and quality characteristics. Meat Sci. 2012, 92, 144–150.
49. Chen, J.X.; Zhao, J.H.; Li, X.; Liu, Q.; Kong, B.H. Composite Gel Fabricated with Konjac Glucomannan and Carrageenan Could Be Used as a Cube Fat Substitute to Partially Replace Pork Fat in Harbin Dry Sausages. Foods 2021, 10, 1460.
50. Alejandre, M.; Poyato, C.; Ansorena, D.; Astiasaran, I. Linseed oil gelled emulsion: A successful fat replacer in dry fermented sausages. Meat Sci. 2016, 121, 107–113.
51. Delgado-Pando, G.; Cofrades, S.; Rodriguez-Salas, L.; Jimenez-Colmenero, F. A healthier oil combination and konjac gel as functional ingredients in low-fat pork liver pate. Meat Sci. 2011, 88, 241–248.
52. Jimenez-Colmenero, F.; Triki, M.; Herrero, A.M.; Rodriguez-Salas, L.; Ruiz-Capillas, C. Healthy oil combination stabilized in a konjac matrix as pork fat replacement in low-fat, PUFA-enriched, dry fermented sausages. LWT-Food Sci. Technol. 2013, 51, 158–163.
53. Salcedo-Sandoval, L.; Cofrades, S.; Perez, C.R.C.; Solas, M.T.; Jimenez-Colmenero, F. Healthier oils stabilized in konjac matrix as fat replacers in n-3 PUFA enriched frankfurters. Meat Sci. 2013, 93, 757–766.
54. Triki, M.; Herrero, A.M.; Rodriguez-Salas, L.; Jimenez-Colmenero, F.; Ruiz-Capillas, C. Chilled storage characteristics of low-fat, n-3 PUFA-enriched dry fermented sausage reformulated with a healthy oil combination stabilized in a konjac matrix. Food Control 2013, 31, 158–165.
55. Campagnol, P.C.B.; dos Santos, B.A.; Wagner, R.; Terra, N.N.; Pollonio, M.A.R. Amorphous cellulose gel as a fat substitute in fermented sausages. Meat Sci. 2012, 90, 36–42.
56. Alejandre, M.; Ansorena, D.; Calvo, M.I.; Cavero, R.Y.; Astiasaran, I. Influence of a gel emulsion containing microalgal oil and a blackthorn (Prunus spinosa L.) branch extract on the antioxidant capacity and acceptability of reduced-fat beef patties. Meat Sci. 2019, 148, 219–222.
57. Schmitt, C.; Sanchez, C.; Desobry-Banon, S.; Hardy, J. Structure and technofunctional properties of protein-polysaccharide complexes: A review. Crit. Rev. Food Sci. Nutr. 1998, 38, 689–753.
58. Chen, C.; Huang, X.; Wang, L.J.; Li, D.; Adhikari, B. Effect of flaxseed gum on the rheological properties of peanut protein isolate dispersions and gels. LWT-Food Sci. Technol. 2016, 74, 528–533.
59. Wang, Y.; Li, D.; Wang, L.J.; Adhikari, B. The effect of addition of flaxseed gum on the emulsion properties of soybean protein isolate (SPI). J. Food Eng. 2011, 104, 56–62.
60. Bi, C.H.; Chi, S.Y.; Wang, X.Y.; Alkhatib, A.; Huang, Z.G.; Liu, Y. Effect of flax gum on the functional properties of soy protein isolate emulsion gel. LWT-Food Sci. Technol. 2021, 149, 111846.
61. dos Santos, M.; Ozaki, M.M.; Ribeiro, W.O.; Paglarini, C.D.; Vidal, V.A.S.; Campagnol, P.C.B.; Pollonio, M.A.R. Emulsion gels based on pork skin and dietary fibers as animal fat replacers in meat emulsions: An adding value strategy to byproducts. LWT-Food Sci. Technol. 2020, 120, 108895.
62. Ran, X.L.; Lou, X.W.; Zheng, H.Q.; Gu, Q.Y.; Yang, H.S. Improving the texture and rheological qualities of a plant-based fishball analogue by using konjac glucomannan to enhance crosslinks with soy protein. Innov. Food Sci. Emerg.

Technol. 2022, 75, 102910.

63. Botella-Martinez, C.; Lucas-Gonzalez, R.; Lorenzo, J.M.; Santos, E.M.; Rosmini, M.; Sepulveda, N.; Teixeira, A.; Sayas-Barbera, E.; Perez-Alvarez, J.A.; Fernandez-Lopez, J.; et al. Cocoa Coproducts-Based and Walnut Oil Gelled Emulsion as Animal Fat Replacer and Healthy Bioactive Source in Beef Burgers. Foods 2021, 10, 2706.
64. Pintado, T.; Herrero, A.M.; Ruiz-Capillas, C.; Triki, M.; Carmona, P.; Jimenez-Colmenero, F. Effects of emulsion gels containing bioactive compounds on sensorial, technological, and structural properties of frankfurters. Food Sci. Technol. Int. 2016, 22, 132–145.
65. Pintado, T.; Herrero, A.M.; Jimenez-Colmenero, F.; Cavalheiro, C.P.; Ruiz-Capillas, C. Chia and oat emulsion gels as new animal fat replacers and healthy bioactive sources in fresh sausage formulation. Meat Sci. 2018, 135, 6–13.
66. Pintado, T.; Ruiz-Capillas, C.; Jimenez-Colmenero, F.; Herrero, A.M. Impact of Culinary Procedures on Nutritional and Technological Properties of Reduced-Fat Longanizas Formulated with Chia (Salvia hispanica L.) or Oat (Avena sativa L.) Emulsion Gel. Foods 2020, 9, 1847.
67. Pintado, T.; Herrero, A.M.; Jimenez-Colmenero, F.; Ruiz-Capillas, C. Emulsion gels as potential fat replacers delivering beta-glucan and healthy lipid content for food applications. J. Food Sci. Technol. 2016, 53, 4336–4347.
68. Serdaroglu, M.; Nacak, B.; Karabiyikoglu, M. Effects of Beef Fat Replacement with Gelled Emulsion Prepared with Olive Oil on Quality Parameters of Chicken Patties. Korean, J. Food Sci. Anim. Resour. 2017, 37, 376–384.
69. Pintado, T.; Ruiz-Capillas, C.; Jimenez-Colmenero, F.; Carmona, P.; Herrero, A.M. Oil-in-water emulsion gels stabilized with chia (Salvia hispanica L.) and cold gelling agents: Technological and infrared spectroscopic characterization. Food Chem. 2015, 185, 470–478.
70. Serdaroglu, M.; Nacak, B.; Karablykoglu, M.; Keser, G. Effects of Partial Beef Fat Replacement with Gelled Emulsion on Functional and Quality Properties of Model System Meat Emulsions. Korean J. Food Sci. Anim. Resour. 2016, 36, 744–751.
71. Nacak, B.; Ozturk-Kerimoglu, B.; Yildiz, D.; Cagindi, O.; Serdaroglu, M. Peanut and linseed oil emulsion gels as potential fat replacer in emulsified sausages. Meat Sci. 2021, 176, 9.