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STRATEGIES FOR REPLACING SATURATED FAT IN MEAT PRODUCTS: A REVIEW

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Keywords: *healthy meat, saturated fat, fat replacer, vegetable oil, emulsion gel*

Abstract
This paper aims to provide a better understanding of how to replace saturated fat in meat products due to concerns about its high amounts as health consciousness improves and consumers look for changes. In particular, we focused on various approaches and technologies to replace saturated fat in meat products. A systematic literature review was conducted using Web of Science, Google Scholar, and Scopus based on existing papers. The use of vegetable oils in meat products, oleogel and emulsion gel technologies, as well as application of protein substitutes were reviewed. The results show that the mentioned methods are potentially effective techniques for reducing the saturated fat content of meat products. As research on new approaches to fat substitutes continues to attract interest, we would like to highlight the research needs for the development of healthy meat products in the long term.

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Introduction

Meat and its derivatives constitute crucial elements of the human diet due to their high-quality protein content and the presence of essential nutrients such as vitamins, indispensable amino acids, fatty acids, and water-soluble minerals, all of which are vital for human biochemistry and physiology [1]. Despite their nutritional value, concerns have arisen regarding the high salt and fat content in these products. To address the issue of excessive salt, an alternative method of processing meat raw materials involves high-pressure processing. This technique offers several advantages, including the creation of stable emulsions, enhanced water retention, prolonged shelf life, and intensified salty flavors [2]. The prevailing perception of meat fat as being high in saturated fatty acids (SFAs) has instilled caution, especially concerning red meat consumption, with concerns linked to adverse health effects such as obesity, type 2 diabetes, hyperlipidemia, elevated cholesterol levels, and cardiovascular diseases [3,4].

Consequently, a key focus of ongoing academic research is the development of healthier meat products. Central to this pursuit is the partial or complete replacement of saturated fats with unsaturated fats, aiming to create products that are more appealing to consumers. However, achieving this objective while preserving the desired sensory qualities inherent in full-fat meat products poses a formidable challenge [4,5]. This challenge is particularly daunting because fats play a pivotal role in enhancing the functional and sensory attributes of meat products, encompassing critical aspects such as texture, tenderness, flavor, and juiciness [6].

Given the rising demand for processed meat items among consumers, scientists specializing in meat science are actively investigating the potential and advantages of employing structured emulsions, such as oleogels and emulsion hydrogels, as viable fat substitutes in an array of meat products. These products include bologna, frankfurters, pâtés, fermented sausages, hamburgers, patties, and meat batters [7]. Meat emulsions consist of a delicate balance of fat, muscle proteins, water, salt, and other ingredients. The interplay between fat and proteins, acting as natural emulsifiers, alongside their chemical interactions, profoundly shapes the final product quality. Significant reductions in fat concentration, alterations in fat particle size, or imbalanced fat-to-protein ratios lead to compromised emulsification capabilities, directly affecting critical aspects such as flavor, aroma, and texture. Thus, a major challenge in making meat emulsion products, for example, frankfurters and bologna, lies in developing stable products that endure cooking processes without experiencing fat and water separation [8]. Concurrently, in the pursuit of healthier meat options, researchers are investigating a blend of olive and chia oil as a substitute for pork fat. Research has demonstrated that substituting a portion of pork back fat with oleogels and emulsion gel systems results in an enhanced lipid profile, marked by reduced saturated fatty acids and increased polyunsaturated fatty acids, ensuring lipid stability during storage [9].

The market for emulsion-based meat products is poised for rapid growth, as companies seize the opportunity to reformulate existing products for health benefits and innovate new, healthier alternatives [10]. Modern consumer lifestyles demand that the meat industry meet evolving expectations, emphasizing the need to deliver increasingly healthier and cleaner meat products. This review aims to provide an academic overview of novel meat processing methods and technologies that reduce saturated fat and offers strategic implications for the industry.

Objects and methods

This review aims to provide an update on the state of research analyzing saturated fat in meat and meat products, with a focus on how new processing methods and technologies can reduce saturated fat in meat products. Below we describe in detail our search strategy, article selection methods, and data synthesis procedures.

Search strategy

For this review, we searched six databases in the areas of food science, food and nutrition, social sciences, and practical sciences, following PRISMA flow guidelines: PubMed, Scopus, ResearchGate, and Google Scholar. The following keyword sets were used as search terms: (a) meat products and saturated fat, (b) meat saturated fat replacement technologies, and (c) meat saturated fat substitutes. Figure 1 is a flowchart showing the process of selecting studies for inclusion in this review.

Eligibility criteria

Articles used in this review had to meet the eligibility criteria, which included selecting studies on saturated fat in meat products, nutritional properties of saturated fat in meat, meat saturated fat replacement technologies, and meat saturated fat substitutes.

Screening and data extraction

Articles were included in the corpus if they (1) investigated the characteristics of meat saturated fat, (2) included meat saturated fat substitution technologies, (3) included consumer perceptions of meat saturated fat, (4) included all types of meat saturated fat substitutes, (5) were peer-reviewed, and (6) were journal articles or conference presentations. We excluded articles that (1) did not target animal fats, (2) did not investigate saturated fat substitutes, or (3) did not introduce a new technology or substance as a means of replacing meat saturated fat. We considered a range of article types, including original articles, full-text articles, Internet articles, summary reports, and series, and did not place restrictions on publication date or language. Exclusion criteria included inaccessible full text, full text without raw data, inappropriate topics, and doctoral dissertations, and we searched through the ProQuest Dissertations and Theses global database.

Study selection and data extraction

A literature review approach was used to select a total of 402 references from the major journal search sites PubMed, Google Scholar, ResearchGate, Medline, and Scopus using the PRISMA flowchart, which resulted in the final selection of 52 articles from a total of 402 articles. The PRISMA flowchart is shown in Figure 1.

Results

Consumer demand for healthy food is steadily increasing around the world. Processed foods high in sodium or fat are criticized for their health effects as consumers' lifestyles and nutritional structures are changing due to a better understanding of the relationship between nutrition and health, and knowledge of food processing is expanding [11].

Vegetable oil as a fat substitute

Beef and pork fat are rich in saturated fatty acids, making them a concern due to their association with coronary artery disease resulting from elevated triglyceride levels in the bloodstream. To create healthier meat products, successful strategies involve substituting or reducing beef or pork fat while enhancing the fatty acid profile [12]. However, from a technological perspective, reducing fat levels in meat emulsions poses challenges, as significant reformulation can detrimentally affect attributes such as flavor intensity and tenderness [13].

One promising strategy involves the integration of vegetable oils, such as olive, soy, sunflower, flax, rapeseed, or marine oils, as fat substitutes. Olive oil, which is widely consumed in the Mediterranean area, has associations with a reduced risk of specific diseases [16]. Approaches involving the incorporation of olive oil, either partially or completely replacing traditional fats in meat emulsions, provide a pathway to align with recommended fatty acid guidelines, yielding meat products that offer enhanced health benefits to consumers [17,18].

This approach provides a compelling avenue for the development of meat products that align with both the technical demands of production and the health-conscious preferences of consumers. In experiments involving a beef model system, the incorporation of olive oil yielded positive outcomes by altering the lipid composition, increasing levels of monounsaturated and polyunsaturated fatty acids, and decreasing the saturated fatty acid content. This not only reduced the overall fat content but also resulted in a meat system that exhibited enhanced oxidative and technological stability. Samples containing olive oil showed lower fat and jelly separation, along with higher water retention compared to the control samples [19]. Likewise, in a research endeavor focused on improving product quality, scientists opted to replace beef fat with an inverted emulsion system comprising olive oil and carrot powder. This replacement led to an increase in unsaturated fatty acids and a decrease in both monounsaturated fatty acids and total fat. The incorporation of carrot powder played a crucial role in maintaining the appropriate technological and oxidative characteristics of the resulting emulsion samples [17].

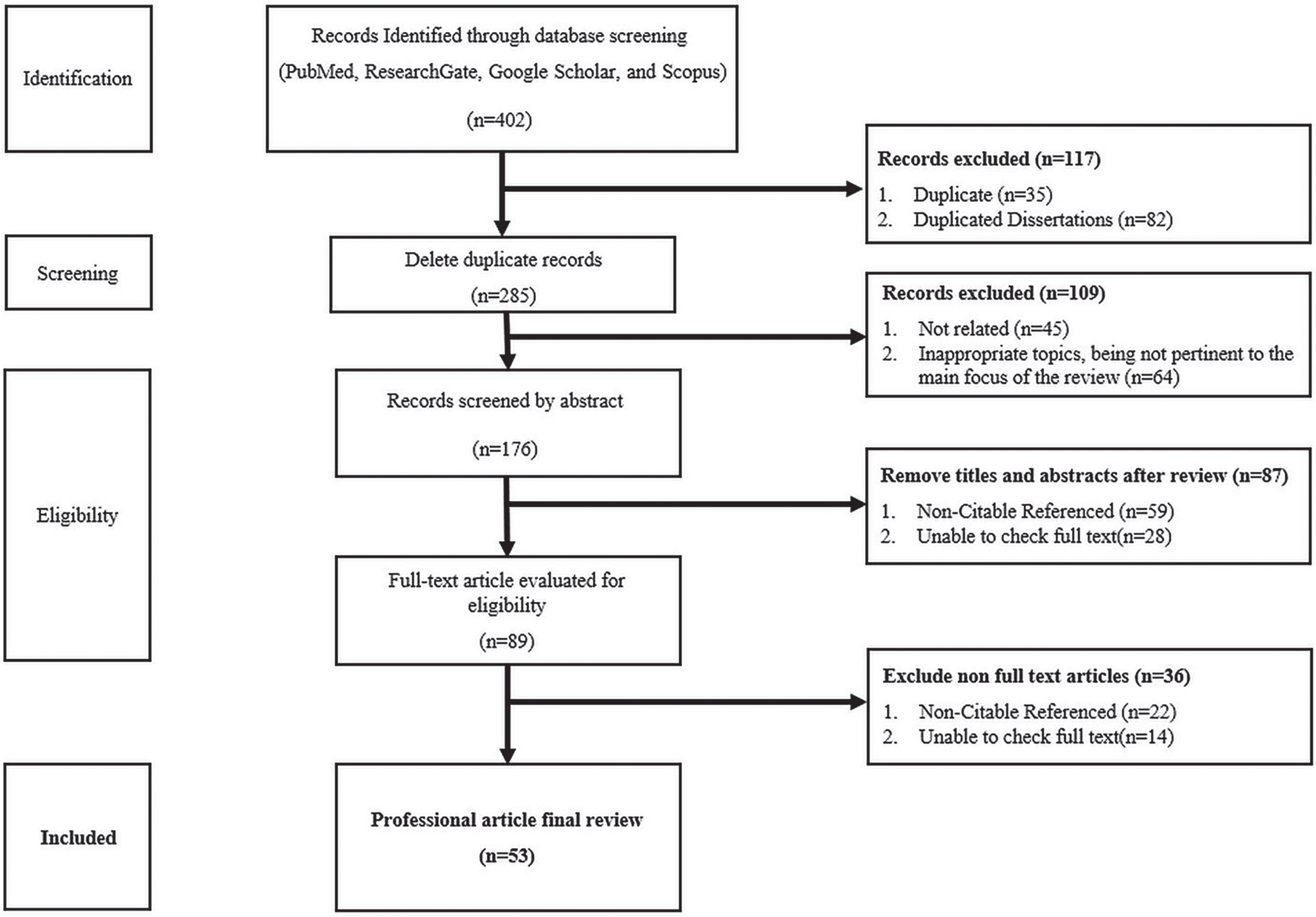

Figure 1. PRISMA flow chart for literature review search results

The increasing awareness among consumers regarding the relationship between food choices and health outcomes has spurred the rapid evolution of functional foods and generated heightened interest in "superfood" products [20]. Acai berry oil, despite its abundance in polyunsaturated fatty acids [21], possesses noteworthy antiproliferative and anti-inflammatory properties without causing genotoxic effects [22]. Additionally, the oil is rich in polyphenolic compounds such as vanillic acid, ferulic acid, catechins, and syringic acid [23,26].

Regarding the analysis of lipid oxidation in foods with acai oil as a fat substitute at 0% (CO), 25% (S-25%), 50% (S-50%), 75% (S-75%), and 100% (S-100%) substitution, the findings (S-100%) revealed that structuring the supplementary fat in the shape of a lyophilized hydrogel emulsion encapsulating acai oil efficiently slowed down the oxidation process [26]. Lipid oxidation, a crucial factor affecting the specificity and sensory quality of meat products, leads to an expanded range of flavors, including undesirable rancidity, while diminishing color parameters and altering texture. These changes ultimately impact consumer acceptance of the product [24,25]. However, in the case of foods with acai oil as a fat substitute, the lipid oxidation values recorded after 7 days of storage (ranging from 0.279 to 0.429 mg MDA/kg sample) were significantly below established thresholds. Moreover, this fat replacement strategy positively influenced the nutritional profile of food by reducing saturated fatty acids (SFAs) and increasing polyunsaturated fatty acids (PUFAs). Notably, the fat replacement approach significantly decreased all analyzed texture parameters, including hardness, springiness, and cohesiveness. These findings highlight that freeze-dried hydrogels encapsulating acai oil can effectively substitute up to 50% of animal fats, thereby enhancing the health benefits of the resulting food product [26].

Protein-based hydrogel emulsions

Alternative substitutes for saturated fats can be effectively incorporated into hydrogels or oleogels [27]. Although oleogels have been thoroughly studied as substitutes for saturated fats, their broad utilization in the food industry faces challenges due to their expensive production processes and the negative impact of organic gelling agents on fatty acid profiles, primarily due to the high polymerization temperatures required. In contrast, emulsion hydrogels offer a more cost-effective solution compared to oleogels and do not necessitate high temperatures for production. Hence, hydrogel emulsions are utilized to immobilize or encapsulate compounds sensitive to heat. Moreover, the oil content in these emulsions does not exceed 50%. The application of such fat substitutes has the prospect of improving the fatty acid composition while simultaneously decreasing the total fat content in food products [27,28].

Emulsions can be structured in the aqueous phase, oil phase, or at the interface. However, the majority of research has concentrated on aqueous-phase continuous emulsions, neglecting oil-phase continuous emulsions. Emulsions formed with oleogels have substantial potential as replacements for trans-fats and for reducing saturated fats in fat-based food products. These emulsions are generated through mechanical forces that encourage the formation of small droplets, complemented by the use of compounds that act on interfaces, thereby reducing interfacial tension [29].

Numerous strategies have been developed to decrease the fat content and enhance the lipid profile of meat products. Among these approaches, the production of fat substitutes using hydrocolloids, emulsification, encapsulation, or gelation of oils has emerged as a prominent method. Utilizing gels enables the creation of fat replacements that exhibit properties similar to those of animal fats, such as comparable rheological, physical, and appearance characteristics. However, these substitutes have a significantly healthier lipid profile due to the incorporation of polyunsaturated oils [30].

Protein-based emulsion gels employed in meat products frequently contain soy protein and sodium caseinate (SC) due to their high nutritional value and their capacity to emulsify, thicken, and form gels [31,34]. Soy protein acts as a surfactant, lowering the interfacial tension between oil and water, thus improving the stability of emulsion gels [32]. Research indicates that soy protein isolate (SPI) can be employed to create emulsion gels with robust freeze-thaw stability and desirable rheological properties when combined with NaCl, underscoring its potential as a fat substitute. However, achieving consistent hardness and gel strength in emulsion gels using proteins proves to be more challenging compared to polysaccharide or protein-polysaccharide complex-based gels [33]. Marie-Christin Baune et al. [35] assumed that increasing the internal phase (oil) content beyond 50% and elevating protein concentration could enhance the rigidity and viscoelasticity of emulsion gels. They investigated commercially available proteins isolated from soy, pea, or potato to create pH-neutral (6.5) and heat-resistant (72 °C) emulsion gels as substitutes for solid animal fats. Their experiments revealed that legume proteins, involving both interfacial and protein-protein interactions, improved structural integrity. The firmness correlated with the cysteine content and interactions were of electrostatic, hydrophobic and hydrophilic nature. Potato protein formed the least stable emulsion, but a stable gel was formed. In general, legume proteins seem more promising for making stable solid animal fat substitutes with a neutral pH that can be shaped and stored for a long time. However, further analysis is needed to provide more accurate information, and research into the effects of salt, which can fuse into emulsions when added to foods, should also be watched carefully [34,35]. Figure 2 provides an overview of the primary gel types used to replace saturated fat in meat products.

Oleogel systems

Oleogel systems are emerging as a viable alternative to traditional fats, which are rich in trans and saturated fatty acids. These systems involve structuring lipids, primarily unsaturated triacylglycerols found in liquid vegetable oils or semi-solids, into gels [36]. Oleogels essentially comprise a liquid organic phase structured by a gelling agent, forming a three-dimensional network capable of capturing oil. Remarkably, oleogels exhibit thermal reversibility and behave akin to solid fats, even in the presence of high levels of unsaturated fatty acids. Importantly, the process of oleogel formation does not necessitate any chemical or structural

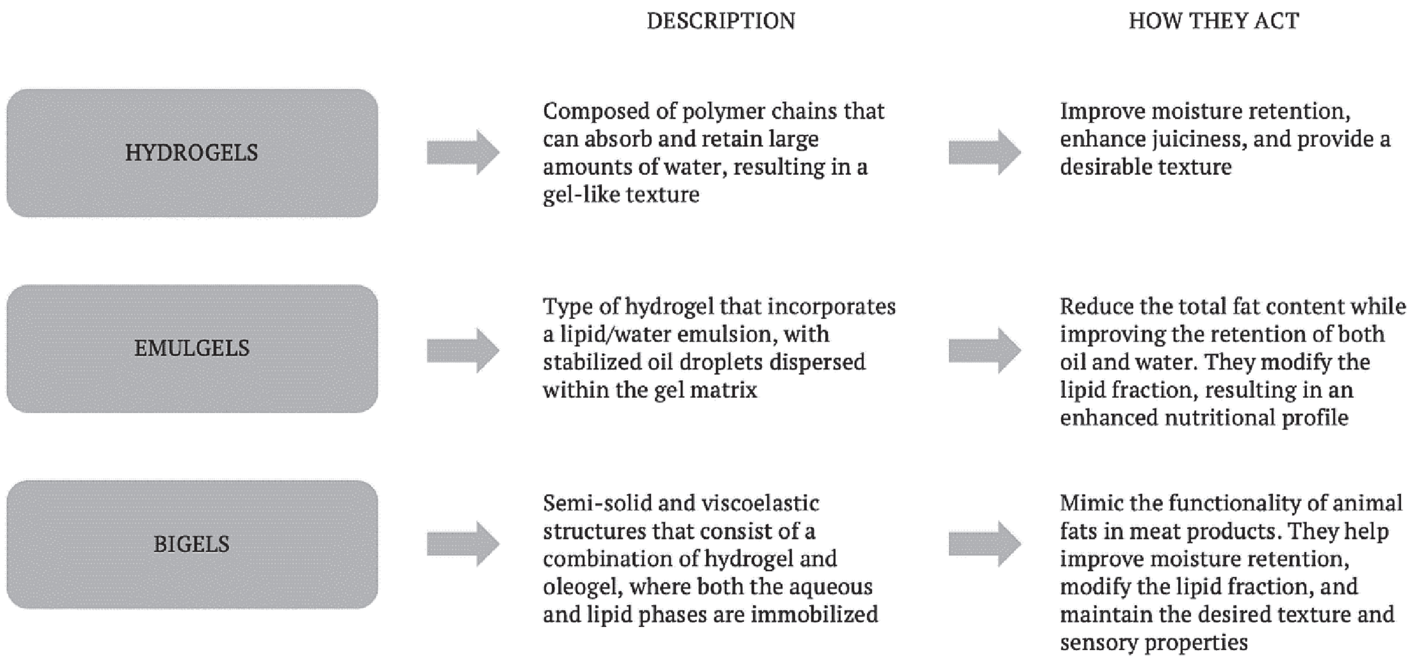

Figure 2. Examples of foods with oleogel [30]

alterations in the triacylglycerol molecule. Consequently, the nutritional properties, unsaturated fatty acid content, and natural regional distribution of the oil used can be preserved [29].

Oleogels are commonly produced by dissolving gelling agents, such as waxes, fatty acids, fatty alcohols, monoacylglycerols, and phytosterols, in vegetable oils at low concentrations. This mixture is then heated above the melting point of the gelling agent and subsequently cooled to form a gel structure [37]. Soybean oil, high-oleic sunflower oil, olive oil, and palm oil are considered viable options for oleogel production because of their advantageous composition, widespread availability, and cost-effectiveness [36]. The amount of a gelling agent needed for gelation decreases with the higher saturation level of the oil. An ideal gelling agent is one that can structure liquid oils at low concentrations, is considered safe for consumption, and exhibits thermally reversible properties. Studying these properties of gelling agents at different concentrations and different vegetable oils is essential for developing diverse oleogels tailored for specific technical applications [29].

Oleogels offer several advantages, including simplifying existing technological processes, producing trans-fat-free and low-saturated products, enabling the creation of low-fat products, and allowing for the enrichment of products with polyunsaturated fatty acids. Additionally, they contribute to cost reduction in manufacturing facilities. Nevertheless, these benefits are accompanied by challenges, including the necessity to adapt existing processes and facilities, preserve sensory attributes, achieve efficient structuring with minimal agents, navigate regulatory hurdles regarding the use of recognized safe structuring agents, maintain thermal and mechanical stability, manage oxidation concerns, and account for the seasonality of specific agents [38,39]. Research on W/O emulsions containing oleogels with sunflower seed wax in rice bran oil and esterified fats demonstrated intricate crystallization dynamics arising from variations in melting properties and chemical composition between the wax esters and fats. Consequently, sausages formulated with these rice bran wax oleogels exhibited properties akin to their fat-laden counterparts, showcasing similar firmness, chewiness, and elasticity while retaining their taste and aroma profiles [40]. Although a variety of food products are being produced from oleogels, further research is needed at various levels to fulfil the potential uses of oleogels. This includes validating the application of oleogels in food products to replace hard fats and understanding the overall impact of oleogels on digestion and metabolism. In addition, flavor development, texture, and physical properties of oleogels and oleogel-formulated foods need to be evaluated; these evaluations may play an important role in consumer acceptance of oleogels in foods. If the mentioned points are addressed, consumer acceptance of oleogel foods can be increased [39]. An overview of oleogel technology applications across various food products, extending beyond meat, is presented in Table 1.

Features of MP112 emulsion

MP112 emulsion, derived from mannoproteins and yeast polysaccharides, serves multiple purposes in the food industry, acting as a dietary fiber, emulsifier, and fat substitute. Created via enzymatic hydrolysis of microbial β-1,6-glucanase glueM, MP112 showcases impressive emulsifying capabilities when used in emulsion formulations. When incorporated into emulsified sausages, a meat product, MP112 emulsion significantly reduced the fat content while elevating the moisture and protein content without compromising organoleptic quality. Particularly noteworthy was its impact on texture that led to enhanced hardness, chewiness, and cohesiveness of sausages, especially at replacement ratios between 50 and 75%. Substituting animal fat with MP112 emulsion resulted in sausages exhibiting enhanced nutritional

Table 1. Applications of oleogels in food as fat replacements [39]

Food products	Liquid oil type	Organogelator type
MEAT PRODUCTS		
Frankfurter	Soybean; canola; sunflower	Rice bran wax; ethylcellulose; y-oryzanol and phytosterol
Meat patties	Linseed; sesame	Oryzanol and β-sitosterol; beeswax
DAIRY PRODUCTS		
Cream cheese and processed cheese products	High oleic soybean; soybean	Rice bran wax; ethycellulose and sunflower wax
Ice cream	High oleic sunflower; sunflower	Rice bran wax; y-oryzano and phytosterols
SPREADS		
Margarine	Soybean	Sunflower wax, rice bran wax, and candelilla wax
Spread	Sunflower; virgin olive and hazelnet	Shellac wax; beeswax and sunflower wax
CONFECTIONARIES		
Chocolate paste	Sunflower; pomegranate seed and palm	Shellac wax; monoglyceride, beeswax, and propolis wax
Chocolate Filling	Sunflower; hydrogenated palm kernel Rice bran and palm; canola	y-oryzano and β-sitosterol; ethycellulose Beeswax; hydroxypropyl methylcelluose and methylcelluose
OTHER APPLICATIONS		
Oleogels as carriers of bioactive compounds	High oleic sunflower; canola	Beeswax with β-carotene; ethycellulose with β-carotene

characteristics, marked by a higher ratio of polyunsaturated fatty acids (PUFA) to saturated fatty acids (SFA) and a reduced n-6/n-3 ratio [41].

To further confirm the effectiveness of the MP112-based emulsion, composite gels of porcine myofibrillar protein and MP112 emulsion were prepared and their gel strength and water holding capacity (WHC) were measured. The results showed that both gel strength (penetration) and WHC improved exponentially with increasing amounts of MP112 emulsion added (10–20%, v/v). An increase in myofibrillar protein gel formation was observed after the addition of lipids and vegetable oils, suggesting that animal fat was partially replaced by mannoprotein MP112 with similar gelling properties [42]. Utilizing diverse emulsions as substitutes for animal fat emerges as an effective strategy to reduce the total fat content in various meat products by replacing fat with water [41].

On the other hand, ultra — high pressure treatment can be used to affect the MP gel, which has the advantage of improving the rheological properties of the MP gel and significantly improving the properties of the gel, creating a more digestible particle size and improving its nutritional value [43]. This idea finds validation in a study carried out by Kavuşan et al. [44], who made fresh chicken sausages using a gelled emulsion infused with black cumin and flaxseed oil. In this study, the chemical composition of uncooked fresh sausages displayed a clear linear relationship with the level of the gelled emulsion, emphasizing the prospect of fine-tuning nutritional attributes through strategic emulsion usage.

Discussion

Exploring diverse methods to substitute animal fats in meat products with non-animal fat ingredients reveals a range of physical forms during processing. These include powders, pastes, vegetable oils, combinations involving dietary fiber, and oleogels and emulsion gels. It is necessary to carry out a thorough analysis delving into ingredients, characteristics, techniques, mechanisms, merits, and drawbacks of these fat replacements. This comprehensive exploration is imperative due to shifting consumer perceptions regarding saturated fat in meat products. Among these approaches, oleogels and emulsion gels have emerged as particularly practical methods. They offer a healthier fatty acid profile compared to other techniques while preserving solid-like properties. Nevertheless, the research findings highlight the challenge of the high expense associated with the oleogel method.

Despite this limitation, oleogels excel in emulating animal fats by dissolving both hydrophobic and hydrophilic elements, while also exhibiting remarkable thermodynamic stability. Furthermore, they enable preserving the nutritional, physicochemical, and sensory attributes of meat products as well as economical manufacturing. Addressing the economic aspects of the oleogel approach is vital for its widespread adoption in the industry [45].

The challenge of replacing saturated fat in meat products

The ongoing trend in food innovation revolves around creating products tailored for vegetarians. However, developing viable vegetarian alternatives presents substantial challenges, both technical and societal. Meat products have unique characteristics related to the amino acid structure, peptide sequences, and intermolecular connections. It is exceptionally difficult to replicate these features in plant-based substitutes, especially concerning sensory aspects. The texture heavily relies on the minute particles that bind water. To preserve these properties, plant proteins must undergo various structuring processes, such as thermodynamic extrusion or shearing. Despite the attempts to alter the structures of plant proteins or improve their ability to retain moisture, significant obstacles remain. A notable example is juiciness, a distinctive characteristic of meat, originating from water absorption and the unique bonding of water with proteins and fibers [46].

Although plant proteins are frequently used as substitutes for meat proteins, they exhibit specific flavors that are absent in meat. For instance, the aftertaste associated with soy in legume protein products is believed to stem from secondary lipid oxidation products. Additionally, replicating the natural reddish or pink color of meat products without resorting to artificial coloring agents presents a significant challenge. This challenge is further complicated by preferences of consumers interested in vegetarian options, who often seek additive-free alternatives, which increase the technical difficulties for food developers [46].

What further unsettles consumers regarding meat protein substitutes is the absence of a clean label: vegetarian products often contain elevated levels of preservatives, stabilizers, colorants, or thickeners, which contradicts the preferences of individuals seeking natural and minimally processed alternatives [47].

Protein substitutes must also serve as nutritional replacements, providing sufficient nutrient density. However, these substitutes, derived from highly processed protein sources, often lack the same nutritional value as meat products sourced directly from the animal. This discrepancy arises because the proteins used in alternative products have already undergone significant thermal and other forms of processing. It remains uncertain whether replacing meat protein with plant-based alternatives might adversely affect human health by reducing the intake of essential components such as heme protein, zinc, or selenium, which are inherent to meat-derived products [48].

Codifying the nomenclature of animal alternatives

With the significant growth of meat alternatives, there is a lack of clarity on whether or not names similar or reminiscent of 'meat' should be allowed when referring to these foods, and how they should be recognized [49]. Recent scholarly reviews, including investigations by Knappila et al. [50], discuss the categorization of protein-rich foods sourced from non-animal origins that were engineered to replicate meat and act as substitutes. These items are often referred to as meat analogs, meat substitutes, or meat alternatives. In line with Fiorentini et al. [51], products made from plant-based ingredients that replicate the sensory properties of meat are commonly termed meat analogs, vegetable meats, or imitation meats. Elzerman et al. [52], in their definition, categorize meat substitutes as products specifically formulated as direct replacements for meat, while they classify meat alternatives as other protein sources typically consumed in vegetarian diets, such as legumes or nuts. On the contrary, as outlined by Choudhury et al. [53], plant-based meat alternatives are viewed as sustainable protein sources capable of imitating the taste, texture, color, and nutritional composition of specific meat types.

Conclusion

Due to health concerns and changing consumer perceptions regarding meat foods, several techniques have been developed to reduce saturated fat in meat foods that are discussed in this paper. Among the ways to replace or reduce fat in meat is the application of emulsion technology using vegetable oils and fat replacer materials. Recent studies have shown their potential for reducing the saturated fat content and producing healthier meat products. However, there is a need for more extensive research into different saturated fat replacement methods and materials to ensure quality and achieve the texture desired by consumers. Future research should go beyond the development of different types of emulsions for saturated fat replacement in meat to evaluate blending methods and formulations that reflect consumer needs in real-world conditions. There is also a need to unify terms that name them for consumers as there are many different meat substitutes and methods.

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