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Vegetable oils in emulsified meat products: a new strategy to replace animal fat

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Abstract

The change in the lifestyle of modern consumers has increased the demand for meat products considered healthier, due tothe addition of animal fat in emulsified meat products, ingredient directly associated with the emergence of chronic diseases such as obesity and hypertension. In this sense, lipid reformulation processes aimed at replacing animal fat with other sources that are considered healthier, such as vegetable oils, appear as an innovative option for the production of meat products. However, it is necessary to develop technological strategies so that these oils can be added without causing undesirable technological and sensory effects to the final product. Thus, this study aimed to review the main aspects of the use of vegetable oils to replace animal fat in emulsified meat products. In general, existing research demonstrates excellent prospects for this new approach to redesign.

Keywords: meat emulsions; microencapsulation; PUFAS; pre-emulsification.

Practical Application: The meat products industry works with the substitution of animal fat for vegetable fat in several products, such as sausage, hamburger, among others. This substitution aims to improve the nutritional and technological characteristics.

1 Introduction

The development of meat products should be seen by the meat industry as an excellent opportunity to conserve and add value to the raw material, promoting differentiation, diversification, and positioning in a market of continuous growth where emulsified meat products such as sausages and mortadella are used (Santos et al., 2018). For example, they are very popular all over the world, being consumed by all social classes due to their low production cost, easy and quick preparation, and also because they meet the sensory expectations of the consuming public, as the lifestyle of modern consumers has- changed significantly in recent years (Sousa et al., 2017; Zeng et al., 2019; Rodrigues et al., 2021; Varadarajan, 2020).

Thus, due to the accelerated population growth, there is a significant portion of consumers concerned about acquiring innovative, quality foods that can still provide beneficial effects on health (Guiné et al., 2020). In this context, the meat industry is influenced to follow the trend of promoting reformulation processes for meat products, for example; sodium reduction, the addition of functional ingredients (Badar et al., 2021), and reduction and replacement of animal fat by vegetable oils (Lima et al., 2021), to still maintain the technological and sensory characteristics of the products (Novello & Pollonio, 2015; Costa et al., 2019; Guiné et al., 2020; Kyriakopoulou et al., 2021).

Among the reformulation techniques for emulsified meat products, the replacement of animal fat with vegetable oils is an excellent challenge for the industry, since fat is a fundamental and crucial ingredient in several properties and technological characteristics of meat products, such as water holding capacity, emulsion stability, shear strength, in addition to sensory attributes such as softness and juiciness (Badar et al., 2021; Oliveira et al., 2021). However, it is noteworthy that the content of animal fat is one of the main concerns of consumers of processed meat products, as this type of fat is related to cardiovascular diseases due to the high consumption of saturated fatty acids, considered harmful (Inmanee et al., 2019; Carvalho et al., 2020).

Some recent studies indicate that consumers' concern about acquiring healthier meat products gave rise to the technique of replacing animal fat with vegetable oils, as they are rich in mono- and polyunsaturated fatty acids that are beneficial to human health (Lima et al., 2021). Consumers increased their consumption of foods rich in Ω-3 and Ω-6, which are fatty acids present in vegetable oils and which can help reduce low-density lipoprotein in the plasma, helping to reduce cardiovascular disease and some types of cancer (Silva et al., 2019; Bis-Souza et al., 2019; Carvalho et al., 2020).

In this scenario, the use of oils rich in polyunsaturated fatty acids, such as flaxseed oil, olive oil, canola oil, and fish oils, to partially replace animal fat in emulsified meat product formulations, can be an alternative to improve the lipid profile of meat products (Cheetangdee, 2017; Alejandre et al., 2019;

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Botella-Martínez et al., 2021). However, this replacement process can have detrimental effects on the shelf life and sensory quality of the products. However, these effects can be minimized through techniques that can stabilize the system so that oil separation in the meat matrix does not occur (Utama et al., 2019).

New proposals for the stabilization and structuring of vegetable oils in the liquid phase were recently indicated as alternatives to saturated fats (López-Pedroso et al., 2020). Thus, pre-emulsification, microencapsulation, and development of organogels (Singh et al., 2017) are examples of technological strategies that can improve the characteristics of vegetable oils. Thus, this review aims to present these main strategies for applying vegetable oils in emulsified meat products. In addition, future trends related to the development of healthier meat products will be presented from the perspective of microencapsulation and structuring of vegetable oils.

2 Importance of Polyunsaturated Fatty Acids (PUFAS) for health

Fatty acids (FA) are carboxylic acids composed mainly of a long, unbranched hydrocarbon chain with an even number of carbon atoms. Most fats in foods are triglycerides, a single glycerol unit combined with three fatty acid molecules. Based on the degree of unsaturation (presence of double bonds), fatty acids are classified into three classes: Saturated (SFA), Monounsaturated (MUFAS), and Polyunsaturated (PUFAS) (Innis, 2011; Ganesan et al.; 2018). PUFAS are classified as omega 3 (ω-3), omega 6 (ω-6), and omega 9 (ω-9), and are so named due to the position of the first double bond from the terminal methyl group of the fatty acid chain (Mariamenatu & Abdu, 2021).

Linolenic acids (ω-3) are found mainly in large amounts in marine fish oils and seaweed and oils and seeds of some vegetables, such as flaxseed and canola. Adequate intake of these acids contributes in the long term to the reduction of LDL-type cholesterol (Low-Density Lipoprotein) (Sokoła-Wysoczańska et al., 2018). Omega 6 (ω-6) offers numerous health benefits since the body needs this fatty acid to work properly. Among the main functions, we can mention the formation of cell membranes, hormonal synthesis, the correct functioning of the immune system, proper retinal formation, neuronal functioning, and transmission of nerve impulses. They can be found mainly in vegetable oils and seeds such as flaxseed, corn, sunflower, and soybean (Mariamenatu & Abdu, 2021).

The relevant importance of PUFAS, especially the ω-3 and ω-6, is since the human organism cannot synthesize them. Thus, they are essential components of the diet, as they exert regulatory functions in physiology and pathological conditions, performing several biological functions such as maintenance of blood pressure, cardiac function, gastric secretion, vascular contraction, platelet aggregation, inflammatory and immune responses. These acids have structural and functional functions, as they provide flexibility, fluidity, and selective permeability to membranes. Thus, consequently, they are of significant physiological and therapeutic significance for human health (Gong et al., 2014; Ji et al., 2014; Bellou et al., 2016).

It is essential to mention that ω-3 and ω-6 fatty acids are metabolically different and have opposite functions, which leads to an essential nutritional balance so that normal development of the body can be achieved, in addition to improving mental health and the prevention of cardiovascular and chronic degenerative diseases (Lange, 2020). Increasing evidence is reported that the balance between ω-3 and ω-6 in brain cell membranes is vital for mental health (Djuricic & Calder, 2021). Using linseed and sunflower oil, (Lange, 2020) stated that it was possible to verify an anti-inflammatory effect of coronary artery disease. According to Collins et al. (2019), PUFAS supplementation during pregnancy has excellent potential to substantially reduce the incidence of preterm birth, which is of significant clinical significance. Satogami et al. (2019) reported in a study that supplementation with polyunsaturated fatty acids results in benefits for body weight.

Clinical and epidemiological research data have suggested that PUFAS are cardioprotective agents (Gilbert et al., 2015; Villalpando et al., 2015; Endo & Arita, 2016; Ganesan et al. 2018), has several beneficial cardiovascular functions, including anti-inflammatory, antiatherothrombotic, antiarrhythmic and antihypertensive (Virtanen et al., 2009; Kitamura et al., 2011). Mozaffarian & Wu (2011) and Ganesan et al. (2018) demonstrated that PUFAS reduce cardiovascular disease and all sudden death factors associated with the heart, in addition to binding to monocyte membranes, regulating cytokine secretion, and inhibiting the generation of the inflammatory response in blood vessels. Thus, Ganesan et al. (2018) state that there is a wide variety of oils rich in PUFAS and antioxidants that offer several health benefits and that can be used to replace animal fat in meat products.

3 Main vegetable oils used as animal fat substitutes in emulsified meat products

The use of vegetable oils in emulsified meat products, acting as a substitute for animal fat, is considered an important pillar. It makes the product more nutritionally healthy (Figure 1) (Badar et al., 2021).

However, it is essential to point out that the acceptance of meat products with reduced animal fat content can be limited by the consumer, where each product category needs a substitute that presents good technological properties with the least possible impact on the overall quality of meat products (Novello & Pollonio, 2015; Ganesan et al., 2018). Thus, the type of vegetable oil used in meat batters affects the fatty acid composition of a reformulated product since, in addition to being cholesterol-free, most vegetable oils have rich sources of MUFAS and PUFAS (Table 1).

The several emulsified meat products were produced with olive oil (Delgado-Pando et al., 2011), sunflower oil (Mora-Gallego et al., 2016), soybean oil (Cheetangdee, 2017), canola oil (Chen et al., 2020), palm oil (Kılıç & Özer, 2019), corn oil (Menegas et al., 2013) and linseed oil (Bolger et al., 2018), which are examples of vegetable oils commonly used in processes of reformulation of emulsified meat products (Novello & Pollonio, 2015).

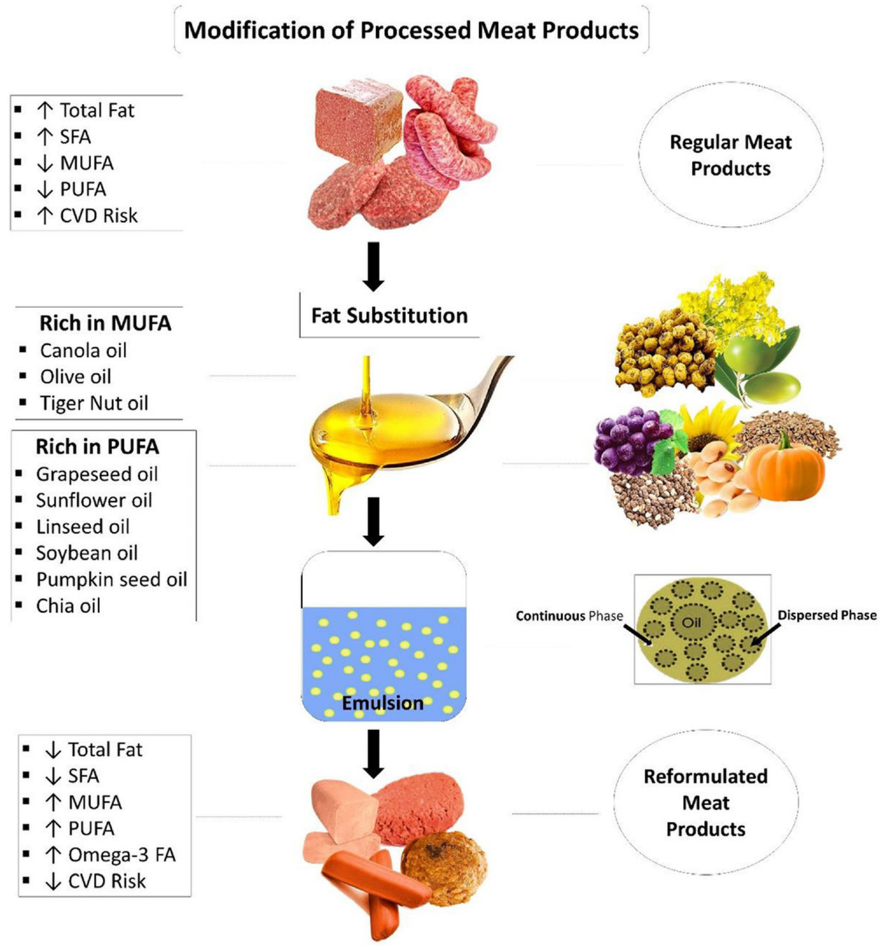

Figure 1. Schematic presentation of the modification of meat products, replacing animal fat with different types of vegetable oils. Fonte: Badar et al. (2021).

Table 1. Fatty acid composition of some vegetable oils used in meat products (% area).

Vegetable oils	Fatty acid (%)		
	SFA	MUFA	PUFA
Olive oil	14	77	9
Sunflower oil	11	20	69
Soy oil	15	24	61
Canola oil	7	61	32
Palm oil	52	38	10
Corn oil	13	29	58
Linseed oil	9	18	73

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids. Source: Adapted from Ganesan et al. (2018).

4 Technological strategies for incorporating vegetable oils into meat products

The development of reformulated meat products is possible, in short, through the establishment of two essential strategies, namely the reduction of unwanted substances and, consequently, the increase in the levels of desired components (Gómez et al., 2018). Thus, the main advantage of using vegetable oils to replace animal fat in meat products is to increase the PUFAS/SFAS (polyunsaturated/saturated) ratio and to decrease the n-6/n-3 ratio.

Lipid oxidation is the primary deterioration reaction of oils and fats and can occur during the processing, storage, or distribution of meat products, limiting shelf life and quality aspects. There is a sequence of reactions to explain the lipid oxidation process, where oxygen reacts with unsaturated fatty acids and occurs in three steps: initiation, propagation, and termination. Products resulting from lipid oxidation, such as hydroperoxides (which are formed in the finishing step), tend to decompose, resulting in the formation of hydrocarbons, aldehydes, alcohols, ketones, among others, which cause undesirable odors and flavors to the products (Yunes, 2010; Das et al., 2020).

However, unsaturated fatty acids in large amounts in vegetable oils are the structures most susceptible to the oxidative process, n directly depending on the degree of unsaturation and the susceptibility to oxidation (Yunes, 2010). Thus, technological strategies are applied as a way to minimize as much as possible the oxidation processes in meat products reformulated with vegetable oils, where, among these strategies, the pre-emulsification of the oil with non-meat proteins (Bolger et al. 2018; Utama et al., 2019; Chen et al., 2020), microencapsulation (Solomando et al., 2020; Heck et al. 2021) and the structuring of vegetable oils (organogels or oleogels) (Singh et al., 2017) are the most common techniques.

5 Pre-emulsification of oil with non-meat proteins

One possibility for inserting vegetable oils in emulsified meat products is to carry out the technique of pre-emulsification of oils with non-meat proteins, an oil-in-water (O/W) emulsions are more accessible to spread in water-based products than the insertion of oil in free form, which can more easily physically separate from the aqueous phase during product storage (Kim et al., 2020). Therefore, this pre-emulsification technique has the main advantage of improving the stability of the system, since the oils can be immobilized in a protein matrix, reducing the chances of the oil physically separating from the product structure, to maintain its stability throughout processing, storage, and consumption (Forell et al., 2010).

Thus, the effects of lipid oxidation in meat products with vegetable oils can be minimized through this technique where the most commonly used ingredients to pre-emulsify the oils before being incorporated into meat products include: Isolated Soy Protein (Josquin et al., 2012; Asuming-Bediako et al., 2014), Whey Protein (Andrés et al., 2009) and Sodium Caseinate (Cáceres et al., 2008), as they are proteins that have excellent emulsifying, stabilizing and texturizing properties.

The pre-emulsification technique is a viable mechanism for non-meat fats used for incorporation into meat derivatives (Badar et al., 2021; Kyriakopoulou et al., 2021). Cáceres et al. (2008) pre-emulsified fish oil with sodium caseinate to verify the effect of this pre-emulsion on the microstructure and sensory properties of Spanish mortadella. The authors reported that the pre-emulsion technique was efficient as it did not interfere with the sensory quality of the prepared samples.

To verify the effect of a combination of healthier lipids on the microstructure, lipid oxidation, nitrite content, microbiological changes, and biogenic amine formation in sausages, Delgado-Pando et al. (2011) pre-emulsified different concentrations of olive oil, flaxseed oil, and fish oil using sodium caseinate and isolated soy protein (PIS). The authors found that this way of inserting the oils into the meat matrix could be an adequate strategy for manufacturing healthier sausages. They also reported that the reformulation process affected the product's characteristics but it did not produce safety problems or restrictions on the sausage's shelf life.

Bolger et al. (2018) evaluated the impact of including linseed oil on the physical characteristics of chicken sausages and added the oil directly to meat batters, pre-emulsified and microencapsulated. According to the study, the formulations developed with pre-emulsified and microencapsulated linseed oil showed greater efficacy when compared to the addition of the oil in the direct form. Thus, it can be stated that the pre-emulsification of the oil minimized its separation from the meat matrix, thus leading to texture improvements and additional benefits such as reduced lipid oxidation and unpleasant taste masking (Josquin et al., 2012; Asuming-Bediako et al., 2014). López-López et al. (2009), when substituting 50% of the animal fat for pre-emulsified olive oil in sausages, they found that they had acceptable sensory characteristics.

Olive oil, corn oil, soybean oil, canola oil, and pre-emulsified grape seed oil were used to replace pork fat in sausages (Choi et al., 2010). The authors found that sausages developed with vegetable oils had low-fat content, energy values, cholesterol levels, and trans fats. However, they showed an increase in pH and also an increase in lipid oxidation (TBARS) compared to the control treatment. The researchers further reported that the addition of vegetable oils contributes to developing low-fat sausages with desirable quality characteristics.

Jiménez-Colmenero et al. (2010) evaluated the influence of replacing pork fat with olive oil in sausages. They stated that sausages developed with different oil-in-water emulsions had good water-fat binding properties, greater hardness, cohesiveness, and chewiness. Replacing fat with a combination of healthier oils (olive oil, flaxseed, and fish) in pork liver pate resulted in a product with, attractive sensory characteristics (Delgado-Pando et al., 2011).

The use of perilla-canola oil pre-emulsified with soy protein isolate was evaluated in the chicken sausage as a substitute for animal fat (Utama et al., 2019). It was found that the perilla-canola oil emulsion (o/w) improved the stability of the emulsion and provided lower cooking losses, also maintaining a good appearance, flavor, and overall impression similar to the control treatment.

To partially replace animal fat in sausages, Chen et al. (2020) used canola oil in free form and pre-emulsified with plasma protein hydrolysates. The authors reported that canola oil, when pre-emulsified, provided an improvement in sausage characteristics when compared to the inclusion of the free form of canola oil.

6 Microencapsulation of vegetable oils

The microencapsulation technique emerged as a new technological strategy for protecting polyunsaturated fatty acids against lipid oxidation. In addition to the technique of pre-emulsification with non-meat proteins, microencapsulation is one of the most favorable alternatives for increasing the oxidative stability of vegetable oils and, consequently, of the meat products to which the oils are added. This technology acts as an actual proper physical barrier to protect bioactive compounds from thermal degradation of PUFAS rich oils. Chemically, there is the incorporation of a compound (core/active) inside another substance (wall/coating/encapsulation). Microparticles have a technological quality similar to pork fat, which is essential factor in maintaining the product's technological properties (Fernandes et al., 2018; Heck et al., 2021).

For the formation of this microencapsulated structure for later application in emulsified meat products, the oil droplets embedded in a homogeneous or heterogeneous matrix are dispersed in a medium, resulting in the formation of a physical barrier between the oil and the medium, thus reducing contact with oxidizing agents (Rios-Mera et al., 2019; Heck et al., 2021). Franco et al. (2017) report that the application of these microcapsules is a highly viable option to maintain the functional characteristics of bioactive compounds present in vegetable oils so that they can benefit consumers by including the possibility of reducing animal fat in meat products.

However, it is essential to note that among the main existing techniques for microencapsulation (spray drying, freeze-drying, complex coacervation, and external ionic gelation (extrusion)), it is necessary to select a method that best suits the specific conditions of each product, where, for example, for emulsified meat products, the microparticles must be resistant to high temperatures, due to the cooking step of these products. This factor is not required for cured raw meat products. In addition, they must also be resistant to variations in product pH and moisture (Bakry et al., 2016; Heck et al., 2021).

Heck et al. (2019) microencapsulated chia and flaxseed oil by external ionic gelation in place of animal fat to evaluate the technological and sensory properties of hamburgers. The authors developed hamburgers with 50% replacement of pork fat by microparticles and found that formulations made with microencapsulated oils had high levels of PUFAS and lower atherogenicity and thrombogenicity rates. The microencapsulation technique improved the technological properties of hamburgers and was considered an effective strategy for developing healthier hamburgers.

Rosemary-enriched chia oil was microencapsulated to replace animal fat in hamburgers, assessing oxidative stability (Heck et al., 2018). The hamburgers were evaluated during 120 days of storage (-18 °C). The formulations containing the microencapsulated oil showed more excellent oxidative stability during the entire period. The use of rosemary allowed a decrease in sensory defects caused by microencapsulation.

Vargas-Ramella et al. (2020) used microencapsulated nut, chia, and linseed oils to replace pork fat in deer meat pâtés. The incorporation of microencapsulated oils resulted in color parameters, smoother textures, and increased PUFAS content. However, the reformulated pâtés presented high lipid oxidation values and lower acceptability values. The microencapsulation technique has also been widely applied to fish oils, which, in addition to vegetable oils, are rich sources of polyunsaturated fatty acids (Heck et al., 2021). Thus, recent researches used microencapsulated fish oils to replace animal fat in emulsified meat products partially, and the results were satisfactory from a technological and health point of view (Keenan et al., 2015; Lorenzo et al., 2016; Pérez-Palacios et al., 2018).

7 Organogels or oleogels

Another technological strategy for incorporating vegetable oils into emulsified meat products is the use of oleogels. These have been characterized as an alternative lipid phase. They are semi-solid systems where a liquid hydrophobic phase is immobilized in three-dimensional lipophilic solids (freezers) (Dassanayake et al., 2011). The ability of a freezer to induce gelation in a liquid medium was attributed to the balance between solubility and insolubility in the solvent (Puşcaş et al., 2020). This dynamic balance allows the freezer to interact both with the continuous phase and itself, giving rise to a network formation (Co & Marangoni, 2012). Among the various available freezers, monoglycerides and phytosterols stand out. The former isis an economically viable option (Co & Marangoni, 2012). The latter attracted interest due to their ability to reduce the LDL cholesterol level in humans by up to 15% (Quílez, 2003).

In this context, implementing oleogels in emulsified meat products constitutes a new approach in question (Barbut et al., 2016a, 2016b; Gravelle et al., 2016). An example of this application is the formulation of frankfurters with the addition of ethylcellulose oleogels (Gravelle et al., 2016). This research did not show significant differences in the hardness and chewing of frankfurters that contain oil gel compared to conventional ones. Frankfurter were formulated with fit-oryzanol phytosterols and organogels and organogel-emulsions (Panagiotopoulou et al., 2016). These findings suggest that further investigation on the topic is warranted (Kouzounis et al., 2017).

Kouzounis et al. (2017) studied the replacement of 50% of pork fat with structured sunflower oil in frankfurter monoglyceride and phytosterol oil gels and found an increase in PUFAS content and no negative influence on physicochemical characteristics, textural and sensorial. Wolfer et al. (2018), on the other hand, developed rice bran wax oil gels to structure soybean oil (100%) to replace animal fat in frankfurter and found a decrease in saturated fatty acids changes in texture. An increase in oxidation with higher organogelatin concentration. Oilgels inside frankfurters maintained their structure throughout the storage period, accounting for 98 days.

Oleogels were also used to promote the insertion of sunflower oil to replace pork fat in the formulation of Bologna-type sausages, where their impact on technological, nutritional, oxidative, and sensory properties was verified (Silva et al., 2019). The authors found that this substitution increased the proportion of oleic acid and decreased the proportion of linoleic acid without changes in oxidative stability.

Alejandre et al. (2019) used canola oil hydrogels and organogels to reduce animal fat in meat masses. The results of this investigation show that these two systems, prepared with different technological strategies, show adequate properties to be used as a total fat replacement in comminuted meat masses. The use of liquid canola oil alone (i.e. unstructured) resulted in undesirable attributes (e.g. texture and color) that could be improved by structuring the oil with organogels or hydrogels emulsions. These gel systems also improved the fatty acid profile of meat masses and reduced lipid oxidation. Organogels were more efficiently incorporated into the meat matrix than hydrogel emulsions, thus showing a more uniform microstructure and no fat loss from the cooked meat batter.

Pintado & Cofrades (2020) evaluated the quality characteristics of healthy dry fermented sausages formulated with a mixture of olive and chia oil structured in oleogel or emulsion gel as a substitute for animal fat. The strategy of reducing and replacing animal fat with a mixture of structured olive and chia oils gives rise to products that maintain the characteristic color of product and a good oxidative and microbiological state during refrigerated storage. Fuels made with EG as an animal fat substitute had a similar hardness to the control, while those with oil gel were softer. However, more studies are needed to improve the sensory attributes of fuels reformulated with this type of lipid material, but no major differences were observed arising from the use of one or the other. Furthermore, the strategy based on the reduction and improvement of the lipid fraction yielded products that remained stable during refrigerated storage.

Martins et al. (2020) review the use of Oleogels for the development of health-promoting food products and build Figure 2. which addresses the stages of incorporation of oleogel in food

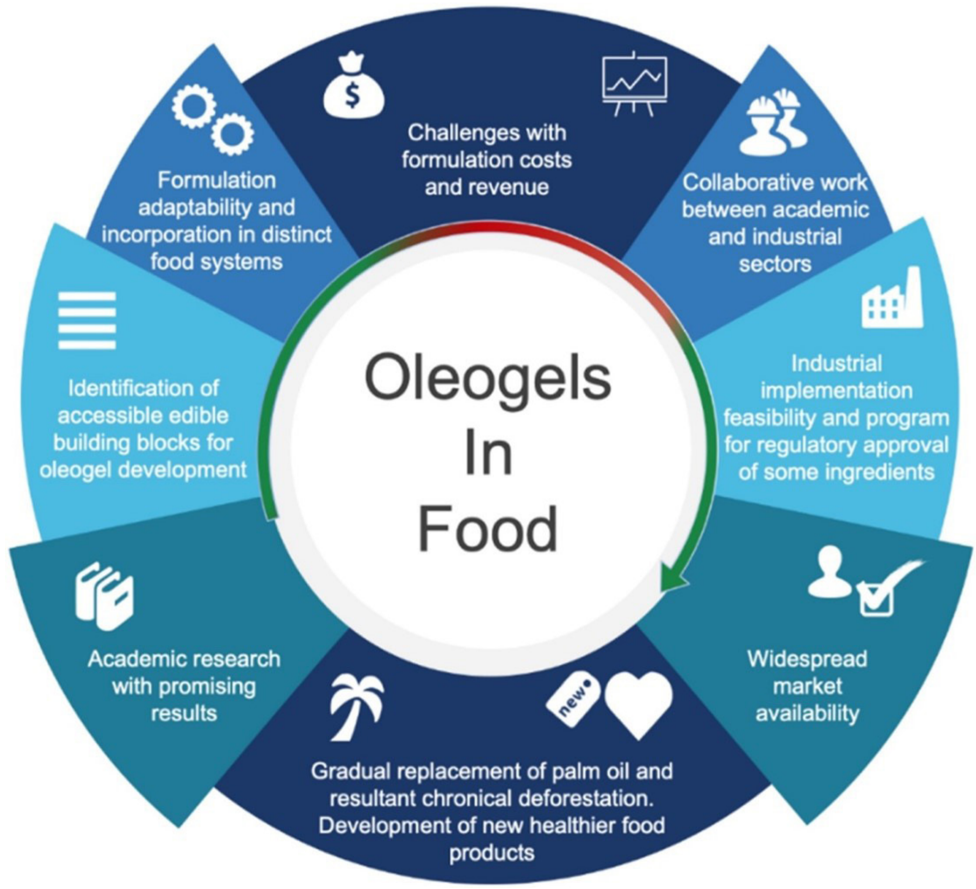

Figure 2. Diagram of the use of oil gel in the food industry. Fonte: Martins et al. (2020).

8 Conclusion

The incorporation of vegetable oils in emulsified meat products is a viable alternative for developing healthier meat products that can meet the expectations of the industry and modern consumers. Thus, scientific studies on the addition of these oils are essential to understand how meat-derived products can be developed with vegetable oils to replace animal fat without affecting the quality parameters of the products. In this sense, technological strategies such as pre-emulsification of oils with non-meat proteins, microencapsulation, and structuring of these vegetable oils are practical tools to incorporate them into emulsified meat products, as they function as physical barriers against oxidation. However, existing research demonstrates excellent future opportunities for applying these technologies to replace animal fat with vegetable oils. However, further studies are needed to improve this replacement due to the numerous challenging opportunities that exist in the emulsified meat products market.

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