Potential utilization of emulsion gels and multiple emulsions as delivery systems to produce healthier meat products

M Serdaroğlu

1 Ege University, Engineering Faculty, Food Engineering Department, 35100 Bornova, İzmir, Turkey

E-mail: meltem.serdaroglu@ege.edu.tr

Abstract. In recent years the increase in consumers’ demands for healthy food have accelerated the studies searching for innovative approaches in meat product formulations. Developing a healthier lipid profile and reducing fat are the most important goals in the meat industry. One of the main problems of animal fat replacement with plant oils is maintaining the technological and sensory properties of the products. Pre-emulsions provide a great opportunity to carry the healthier plant oils to meat systems for increasing mono and polyunsaturated fatty acid content, since adding liquid plant oils directly to product formulation can have technological and sensory problems. Using emulsion gels and multiple emulsions prepared with polyunsaturated oils could be a good option to achieve healthier meat products. This review addresses the emulsion gel and multiple emulsion properties and their use in meat products as fat replacers.

1. Introduction

Meat is a valuable food that should be included in the daily diet due to meat’s biologically active proteins and essential minerals. Fresh meats are processed into meat products using various technologies and formulations to extend their shelf life and diversify consumption. Processed meat and poultry products like fermented sausages, emulsion-type sausages, and patties contain high amounts of saturated fat and cholesterol. However, it is very well known that excessive saturated fat intake has been associated with various chronic diseases, such as obesity, hypertension, and an increased risk of cardiovascular diseases [1,2] The increase in consumers’ awareness of meat consumption and health has prompted the meat industry to develop healthier product formulations. Fat reduction and modification of fatty acids are the most important current approaches to the development of healthier meat product formulations [3].

For this purpose, scientists are reformulating meat products by reducing animal fat, improving the n-6/n-3 ratio, and increasing the amount of unsaturated fatty acids, to produce products with quality criteria equivalent to products produced with standard methods [1]. It is possible to use those oils of plants and/or animal origin that contain high levels of unsaturated fatty acids, instead of saturated fat from animals. However, considering the product quality, reducing fat, and using plant oils instead of animal fat in the formulation is not a simple task. The fat used in meat products affects the technological quality and sensory properties such as flavor, juiciness, texture, and mouthfeel. Furthermore, liquid oils containing high levels of unsaturated fatty acids can cause undesirable flavor changes [4] and the formation of toxic compounds in the products due to their susceptibility to oxidation [5].

Thereby, to overcome the mentioned disadvantages, novel lipid modification strategies to stabilize and structure highly unsaturated liquid oils have been investigated. Structuring highly unsaturated oils exhibits a more feasible way of maintaining reformulated systems with properties equivalent to the meat products formulated with saturated fat [1,6,7]. Within this framework, the novel emulsion gels and multiple emulsion systems are emphasized to provide considerable advantages since they could provide structural reinforcement and thereby improve the stability, texture, and functional properties [7,8,9,10,11,12]. They could also improve oxidative quality [13]. The addition of structured oils to meat product formulations increased the textural, sensory, and technological properties and provided better...
oxidative stability [14]. The main objective of this review is to demonstrate the properties of emulsion gels and multiple emulsions which can be used to reduce fat and modify the fatty acid composition of meat products, resulting in healthier formulations.

2. The use of gelled emulsions in meat products

Emulsion gels are emulsion systems with a gel network structure and solid mechanical properties as seen in Fig. 1 [8,15]. Production is carried out in two stages. In the first stage, the oil and water phases are emulsified with various proteins. Then, the liquid emulsion becomes viscous with the effect of clumping of emulsion droplets or gelling of the continuous phase as a result of heating, enzyme, or acidification processes [16,17]. An oil-in-water emulsion with a low viscosity continuous phase exhibits liquid-like properties unless it contains high amounts of oil. However, if the continuous phase is a viscous liquid or gel, the emulsion will also have viscoelastic behavior, indicating that the gel emulsions will also affect the texture of the product to which they are added [18]. Numerous proteins from milk, soy, and egg have been used in protein-stabilized emulsion gels, in which heat treatment, acidification, and enzyme treatment (trans-glutaminase) are the main protein gelation methods [16].

![Figure 1. Preparation of emulsion gels (Lu et al., 2019)](image)

In the production of emulsion gels, hydrocolloids and polysaccharides can be used as thickeners and stabilizing agents (apart from proteins) or because of their positive effects on health [19,20,21]. This feature of emulsion gels allows us to classify them as a method that can be used to solve the quality problems that arise when oil is used instead of animal fat in the formulation. With the addition of emulsion gel to the formulation, healthier product production is ensured, while the shelf life of the product is extended without changing the quality of the product.

The use of emulsion gels in various meat products has made it possible to obtain products with reduced fat content and improved fatty acid profile and n-6/n-3 ratio. Total fat reduction of up to 30% could be achieved in heat treated fermented sausages by replacing animal fat with hot-set emulsion gel formulated with linseed and peanut oil. Similar studies reported significant fat reductions in beef patties [22] and Bologna sausages [13] that were formulated with different emulsion gel systems as animal fat replacers. Table 1 shows the effects of using emulsion gels in meat product formulations. When the results of studies are examined, it is seen that using emulsion gels prepared with various plant oils in meatball and sausage formulations resulted in products with desired quality and technological properties [8, 20,23, 24]. Aleandre showed that when the pork fat of fermented sausage was replaced with an emulsion gel prepared with carrageenan and flaxseed oil, the energy value was decreased, the polyunsaturated fatty acid composition improved, and the n-6/n-3 ratio was obtained as 10.20 [7]. Better understanding of the behavior of emulsion gels in meat systems is important to guarantee the quality of the final product [20]. Incorporating emulsion gels into formulation can improve the technological
properties such as cooking yield, water, and fat binding capacity of meat products. Moreover, emulsion gels could be a more suitable alternative than simple oil-in-water emulsions to achieve better characteristics such as higher water holding capacity, better texture, and lower cooking loss in model system beef emulsions [20], in chicken patties [8], and fresh chicken sausages [11]. In chicken patties, replacement of beef fat with emulsion gel at a level of 50% resulted in similar cooking characteristics with control patties that contained 100% beef fat [8]. Meat products with incorporated mono or polyunsaturated oils are exposed to oxidation and quality deterioration. Therefore, these oils should be protected to make them more stable against oxidative changes during processing and storage [25]. In this respect, emulsion gels create an opportunity to incorporate healthy oils into meat products to protect the oils against oxidation by gelled structure. Replacement of beef fat totally by a hot-set emulsion gel system retarded oxidation due to the capsulated oil droplets in the gel matrix acting as a protective barrier [26]. A similar pattern was shown in fermented sausages produced with emulsion gel prepared with fig seed oil, and 100% replacement of beef fat showed a more protective effect against oxidation compared with 50% replacement level [27].

### Table 1. The use of emulsion gels in meat product formulation

| Product | Emulsion gel | Result | Reference |
|---------|--------------|--------|-----------|
| Model system meat emulsion | Extra virgin olive oil, milk, and gelatin | Decreased pf | [23] |
| Frankfurter | Olive oil, chicken seed flour, MTF, alfalfa, and gelatin | Improved technological properties (water holding, emulsion stability) up to 50% replacement, better hardness, and palatability | [24] |
| Chicken patties | Extra virgin olive oil, milk, and gelatin | Denitrocellulase effect on all investigated cooking characteristics when hard fat completely replaced with gelled emulsion | [1] |
| Model system meat emulsion | Extra virgin olive oil, milk, and gelatin | Higher b values observed with respect to control | [23] |
| Meatsauce | Olive oil, milk, and gelatin | Lower fat content, Improved emulsion characteristics in terms of emulsion stability, water holding capacity and crack yield, and less expensive oil when used as completely lipid source | [23] |
| Low fat meat | Microcrystalline cellulose and gelatin | Lower 6:0 and increased 3:0 | [29] |
| Fresh sausage | Extra virgin olive oil, chicken seed flour, and bran | Lower energy value due to reduced fat content, Improved sensory properties | [20] |
| Riaju sausage | Canola oil, sodium caseinate, and caseinates | No changes in protein content and moisture content, Increased moisture content, and b values for cooked meat | [20] |
| Reduced fat beef patties | Microcrystalline cellulose and gelatin | Significant fat reduction and improved lipid profile, Improved emulsion properties at the addition of extract Low hardness, and higher antioxidant activity with the addition of extract | [22] |

3. **The use of double/multiple emulsions in meat products**

Double or multiple emulsions are called “emulsion of an emulsion” [33]. Multiple emulsions with low thermodynamic stability are emulsions that combine both oil-in-water (W/O) and water-in-oil (W/O) systems. These emulsions have three phases, two water-oil interfaces and two separate emulsifiers [34]. There are two multi-layer emulsion systems (Fig. 2), W1/O/W2 (water-in-oil-water) or O1/W/O2 (oil-
in-water-oil). In W1/O/W2 emulsions, there is an oil-soluble emulsifier to stabilize the inner water droplets, and a water-soluble emulsifier to stabilize the oil droplets in the outer water phase [35].

Replacing a significant portion of the oil in the droplets of an emulsion with small water droplets does not significantly alter the rheology unless the volume fraction of the outer droplets in a multiple emulsion is high. It is, therefore, a good option to use multiple emulsions for fat reduction applications in foods [36]. In meat products, W1/O/W2 emulsions are often used to reduce animal fat in the formulation, improve the fatty acid profile, reduce lipid oxidation, and encapsulate vitamins, minerals, bioactive and sensitive components [1, 37].

For this purpose, in various studies on meat products and model systems, sodium caseinate, whey protein, egg white powder, and beet juice were used as emulsifying agents, and olive oil, chia, perilla oil, and sunflower oil as oil sources. Thus, meat products with enhanced fatty acid profiles have been developed [34,37,38,39,40]. The effects of using double/multiple emulsions in meat products can be seen in Table 2. Model system beef emulsions produced with multiple emulsions prepared with olive oil and sodium caseinate had better stability and modified fatty acid composition compared with those produced with beef fat [34].

![Figure 2. Preparation of W/O/W emulsions (McClements, 2012)](image)

**Table 2. The effects of using double/multiple emulsions in meat products**

| Product | W/O/W emulsions | Results | References |
|---------|-----------------|---------|------------|
| Sausage | Perilla oil, pork back fat, sodium caseinate | Modified fatty acid composition: 60% reduction of the fat content, higher L* and lower a* value, enhanced antioxidant activity | [30] |
| Model system meat emulsion | Olive oil and sodium caseinate | Decreased fat and increased protein content, enhanced fatty acid composition, reduced lipolysis | [31] |
| Model system meat emulsion | Olive oil, sodium caseinate, gelatin, HWT | Improved water binding properties, increased L* and lower a* value | [32] |
| Pork patty | Perilla oil, sodium caseinate, gelatin, HWT | Improved oxidative stability by the addition of extract, higher pH and lower a* value | [33] |
| Model system meat emulsion | Sunflower oil, whey protein isolate, beet juice | Increased total phenols, ABTS, and DPPH. | [34] |
| Model system meat emulsion | Olive oil, fish oil, sodium caseinate, and olive leaf extract | Improved moisture and reduced cooking yield, reduced a* value | [35] |
| Reduced-fat meat batter | Soybean oil, whey protein concentrate, and Perilla leaf extract | Reduced lipid oxidation, reduced cooking yield, reduced cooking loss, and improved texture | [36] |
| Meat emulsion | Canola oil, soy protein isolate, and sunflower extract | Lower fat and higher protein content, improved binding properties, and better texture | [37] |

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4. Conclusion

Emulsion gels and multiple emulsions are the carriers of healthy oils in meat product formulations. These emulsion systems prepared with vegetable oil, proteins, and hydrocolloids can replace animal fat. Numerous plant oils or marine oils have been used to partially replace animal fat in meat products. They can be used successfully in meat product formulations to reduce fat and provide fatty acid modifications. Their effects on the technological and sensory quality of meat products vary depending on the proteins, hydrocolloids in the formulation and the character of the oil carried into the system.

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