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Review

Role of interfacial protein membrane in oxidative stability of vegetable oil substitution emulsions applicable to nutritionally modified sausage

Jiang Jiang [a], Youling L. Xiong [b,*]

[a] School of Food Science and Technology, Synergetic Innovation Center of Food Safety and Nutrition, Jiangnan University, Wuxi, Jiangsu 214122, China
[b] Department of Animal and Food Sciences, University of Kentucky, Lexington, KY 40546, United States

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ABSTRACT

The potential health risk associated with excessive dietary intake of fat and cholesterol has led to a renewed interest in replacing animal fat with nutritionally-balanced unsaturated oil in processed meats. However, as oils are more fluid and unsaturated than fats, one must overcome the challenge of maintaining both physical and chemical (oxidative) stabilities of prepared emulsions. Apart from physical entrapments, an emulsion droplet to be incorporated into a meat protein gel matrix (batter) should be equipped with an interactive protein membrane rather than a small surfactant, and the classical DLVO stabilization theory becomes less applicable. This review paper describes the steric effects along with chemical roles (radical scavenging and metal ion chelation) of proteins and their structurally modified derivatives as potential interface-building materials for oxidatively stable meat emulsions.

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1. Introduction

An emulsion is a heterogeneous system consisting of one or more discontinuous matter(s) dispersed in a continuous phase. For example, an emulsion can be an oil-in-water (O/W) system or a water-in-oil (W/O) system. Both types of emulsions are widely designed in the

* Corresponding author.
E-mail address: ylxiong@uky.edu (Y.L. Xiong).

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cosmetic, skin care, and pharmaceutical industries, but the former is far more prevalent in food. If the oil droplets are less than 1000 nm in diameter, an O/W emulsion is considered a colloidal dispersion because the particles are evenly distributed throughout the solution and invisible to the naked eye or imaging instrument at regular microscopic scale (Walstra & Oortwijn, 1982).

Cooked meat prepared from finely chopped or milled fresh muscle and fat, such as frankfurters, wieners, and bolognas, are considered emulsion products. In reality, however, they very little resemble a true O/W emulsion, for example, the physical structure, morphology, consistency, and oxidative stability. Hence, in the meat industry, many prefer the term "meat batters" to describe emulsified meats. Essentially, a meat batter is a multi-phase, complex system comprised of finely dispersed fat particles, soluble proteins, and various hydrated or insoluble substances, such as muscle fibers and fiber fragments, myofibrils, collagen fibrils, and nonmeat proteins. Fat particles in these products typically range from 1 to 50 μm in diameter, which are immobilized in a protein matrix, and their presence imparts flavor, juiciness, as well as mouthfeel.

Emulsion-type meat products, similar to coarse-ground sausage, can contain as much as 30% or more fat. The abundance of saturated fat and cholesterol raises the concern about the potentially negative impact on the consumer's health. Therefore, for much of the past three decades, there have been advocates from consumer groups and health professionals to limit the consumption of processed meats, particularly those containing high amounts of fat. Despite conflicting research reports and general controversies around the issue, regular consumption of high-fat and high-cholesterol products is known to predispose consumers, especially those with chronic circulation problems, to the risk of cardiovascular diseases and complications (Houston et al., 2011). Moreover, high dietary fat intake contributes to the growing epidemic of obesity, a serious nationwide health concern.

To address the animal fat issue, researchers have long been exploring unsaturated fatty acids from vegetable oils and certain marine oils as possible replacements for fats containing high amounts of cholesterol, for example, in frankfurter-type sausage production (Álvarez et al., 2011; Jiménez-Colmenero, 2007; Youssef & Barbut, 2009). Of particular interest is the substitution for animal fat (lard or tallow) in meat emulsion products with selective vegetable oils that are abundant in ω-3 fatty acids (e.g., α-linolenic), ω-6 fatty acid (e.g., linoleic) or ω-9 monounsaturated fatty acids (e.g., oleic) (Alvarez, Castillo, Payne, & Xiong, 2009; López-López, Cofrades, & Jiménez-Colmenero, 2009; Toldrá & Reig, 2011). Special attention has been given to the ω-6 to ω-3 ratio. Biochemical and clinical studies have shown competitive metabolism of ω-6 and ω-3 fatty acids by the same pathway; however, for optimum health, a desirable ω-6:ω-3 ratio was thought to be approximately 3:1, much less than the level (as high as 15:1) found in modern Western diets (El-Badry, Graf, & Clavien, 2007). Although some diseases, including breast cancer and asthma, may be associated with a higher ω-6:ω-3 ratio, large trials have shown that reductions in cardiovascular risk are often linked to the total amount of ω-3 fatty acids rather than the specific ω-6:ω-3 ratio (Griffin, 2008).

The potential nutrition and health benefits of producing formulated meat products high in polyunsaturated fatty acids (PUFAs) seem to be evident: reduced risk of coronary heart disease and less susceptibility to carcinogenesis caused by over-consumption of saturated fatty acids and cholesterol. A controlled seven-week metabolic study on humans showed that those receiving a canola oil diet (equivalent to 28% of dietary energy) had a 20% decrease in plasma total cholesterol and a 25% reduction in LDL when compared with those on the control diet without canola oil (McDonald, Gerrard, Bruce, & Corner, 1989). There have been considerable investigations on the textural properties of meat emulsions containing vegetable oils as a partial replacement of animal fat, and the work has resulted in many patents and commercial incentive trials (Asuming-Bediako et al., 2014; Poyato, Ansorena, Berasategi, Navarro-Blasco, & Astiasarán, 2014).

To be successful in the implementation of vegetable oils as an alternative product strategy, especially oils with a high proportion of PUFAs, two obstacles must be overcome: physical instability due to the fluidity of vegetable oils and oxidative instability due to the high degree of unsaturation (Cáceres, García, & Selgas, 2008; Salminen, Herrmann, & Weiss, 2013). For both, an improved stabilization will critically depend on the structural and chemical properties of the interfacial membrane enveloping the oil droplets. Proteins forming the interfacial coating may act as a physical barrier that separates lipid molecules from prooxidants present in the aqueous phase. Hence, the structure of adsorbed proteins as well as the emulsion droplet size influences the rate of lipid oxidation. On the other hand, the chemical nature of an antioxidant, including scavenging of radicals and chelation of metal ions by reactive amino acid residue side chain groups, would further complement the physical effect and enhance the overall antioxidant efficacy of proteins. Other factors include the composition and structure of the protein matrix within the meat batter that act to entrap oil droplets. A protein gel filled with pre-emulsion offers a possible mechanism to minimize oil release and improved mechanical strength and water-holding capacity. Prepared vegetable emulsion droplets have been imbedded in immobilizing materials such as hydrogels then appropriately fabricated to allow blending into the meat batter (Poyato et al., 2014).

This review article presents a brief discussion of the research on the generation of protein-based interfacial membranes for vegetable and other PUFA oil emulsions intended as fat replacements in alternative comminuted meats. The focus is on the physical and chemical effects of the designed emulsion interfacial membrane in the process of developing oxidatively-stable, nutritionally-balanced meat products. It is noted that while results from some of the reported studies have been patented, tested at a pilot scale, or already implemented in commercial meat processing, some of the ideas remain conceptual requiring further exploration. Sensory attributes, particularly flavor, of such replacement oil emulsion meat products, irrespective of oxidation, are not specifically discussed but can be found in a limited number of publications included in the reference list.

2. Theory of emulsion stabilization

2.1. Traditional meat emulsions

The physicochemical stability of a protein-based emulsion depends on the structure of adsorbed protein layers and whether other surfactants are present (Dickinson, 1992; Wong et al., 2012). The specific structure of the interfacial protein layer(s), thus, the emulsifying properties, is derived from the inherent structural characteristics of the protein, for example, a flexible structure with random coils in β-casein (Dickinson, Rolfe, & Dalgleish, 1988; Evers, Andersson, Lund, & Skepö, 2012), an elongated fibrous structure in myosin (Galluzzo & Regenstein, 1978b; Hong, Min, & Chin, 2012), and a compact globular structure in β-lactoglobulin (Zhai et al., 2011).

The stability of a meat emulsion is conferred by two general mechanisms: the interfacial membrane and the protein matrix in the continuous phase. The formation of a protein coating having a thickness of several nanometers around the oil droplet provides electrostatic and steric repulsive forces between emulsion droplets (Dickinson, 2010). Macroscopically, fat particles with a more or less rigid coating, largely made of salt-extracted myofibrillar proteins, are entrapped in a protein matrix and stabilized by a three-dimensional gel structure formed upon cooking. Within the protein matrix is also a large amount of water immobilized through capillary forces. The co-existence of various soluble and insoluble constituents in finely chopped meat makes it a tacky, semi-solid paste, hence, the name "meat batter". It is important to draw the distinction between a meat emulsion and a classical "oil-in-water" emulsion. The latter, often dilute and of a high fluidity, is a system where oil droplets stabilized by an amphiphilic surfactant, called an emulsifier, are suspended in a pure or homogeneous aqueous phase.