



## Review

## Structuring food emulsions in the gastrointestinal tract to modify lipid digestion

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## ABSTRACT

The importance of nutrient lipids in the human diet has led to major advances in understanding the mechanisms of lipid digestion and absorption. With these advances has come new recognition that the matrix in which lipids are presented (i.e. food structure) in the diet could influence the rate of lipid digestion and hence the bioavailability of fatty acids. As a consequence, there is growing interest in understanding how food material properties can be manipulated under physiological conditions to control the uptake of lipids and lipid-soluble components.

The lipids in many, if not most, processed foods are normally present as emulsions, which can be end products in themselves or part of a more complex food system. In this review, we discuss the formation and properties of oil-in-water (O/W) emulsions, especially how these emulsions are modified as they traverse through the gastrointestinal tract. Among other factors, the changes in the nature of the droplet adsorbed layer and the droplet size play a major role in controlling the action of lipases and lipid digestion. Greater knowledge and understanding of how the digestive system treats, transports and utilizes lipids will allow the microstructural design of foods to achieve a specific, controlled physiological response.

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## 1. Introduction

Through assiduous research, the science of nutrition has identified all of the vitamins, minerals, amino acids and fatty acids that are essential to the growth and reproduction of animals and humans. The foods that we eat are composed of some or all of these elements, and it is now being belatedly recognized that the matrix in which they are presented has an impact on their availability at the point of utilization in the consumer body. As society has become more affluent, it has recognized the pleasurable aspects of

eating, as comfort or reward, to satisfy, delight or stimulate the senses. The food industry has not been slow to recognize this opportunity for adding value and, as a result, much effort has been directed to achieving acceptable texture and sensory properties in the product. Texture perception and related events such as flavour release are inextricably linked to disintegration and breakdown of the food structure during mastication [1,2]. Both taste stimuli and odour stimuli can be detected only if they are released effectively and efficiently from the food matrix. The modern food industry currently transforms natural raw materials into a large number of products with palatable structures to gain acceptability from the consumer. The shelf life, physical and rheological behaviour, and textural and sensorial traits of these fabricated foods depend

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on the architecture of the matrix. Their digestibility and their subsequent utilization as a source of nutrients have frequently played no part in their conception, design or consumer appreciation.

Possibly, there are niche opportunities for products with particular properties that will provide selectable benefits, but tackling the major food-linked health issues of obesity, cancer and cardiovascular diseases requires greater knowledge and understanding of how the digestive system treats, transports and utilizes the major food components, minerals, proteins, carbohydrates and lipids [3]. In this review, we consider the behaviour of the lipid components of foods.

Dietary lipids, fats (if they are solid) and oils (if they are liquid), are derived from both animal sources and plant sources. These lipids may be further characterized by their function as storage lipids, potential sources of energy by  $\beta$ -oxidation, or membrane lipids. Cytoplasmic or plasma membranes contain about half their dry mass as lipids. Major components include phospholipids (up to 65%), glycolipids (up to 20%), sterols (up to 5%) and non-polar lipids including hydrocarbons, diacylglycerols and pigments [4].

Triacylglycerols or triglycerides (TAGs) form the major component of storage lipids, often representing more than 95% in refined edible oils and as much as 99% in the fat of animal adipose tissue. The physical properties of a TG are determined by the specific fatty acids esterified and the actual positions occupied by the fatty acids. Each of the three carbon atoms of the glycerol backbone allows for a stereochemically distinct fatty acid bond position, designated sn-1, sn-2 and sn-3. A TG with three identical fatty acids is rarely found in nature. Two or three different fatty acids are the norm. The melting point of the TG is determined by the positions of the fatty acids and their physico-chemical properties – their chain length, their position and the conformation of any double bonds they possess. Mono- and acylglycerols have one and two fatty acids respectively esterified to glycerol. They rarely occur in large quantities in nature, but are primarily intermediate products of TG digestion. However, mono- and diacylglycerols may feature in manufactured foods, as emulsion stabilizers.

Dietary phospholipids, a major component of membrane lipids, are also esters of glycerol but, as well as fatty acids esterified to the sn-1 and sn-2 positions, phosphoric acid is esterified to the sn-3 position, and this phosphoric acid, in turn, may be further esterified to other alcohols. This confers a polar character on this region of the phospholipid, giving these molecules a distinctly amphipathic structure – hydrophobic properties conferred by the fatty acid chains and hydrophilic properties conferred by the polar head groups. The most common phospholipids are phosphatidylcholine, phosphatidylethanolamine, phosphatidylinositol and phosphatidylserine. The polar nature of the phospholipids makes them much more soluble in water than the hydrophobic TGs. Their amphipathic structure encourages them to form bilayers and lamellar structures, making them a critical structural component of all cell membranes, both plant and animal. Further, their amphipathic properties are utilized by nature in promoting the emulsification of TGs as lipid droplets in the storage cells of plants, animals and aqueous solution microorganisms. The phase behaviour of separated polar lipids and the structures they adopt, both lamellar and non-lamellar, have been reviewed recently by Leser et al. [5].

The lipids from plant and animal sources that we consume in our diet perform in those entities the same critical functions that lipids perform in the human body. They provide a concentrated source of energy, slightly more than twice that from protein or carbohydrate on a weight basis. Any lipid excess to immediate energy requirements is stored in fat depots, colonies of adipocytes, loaded with lipid droplets, in various parts of the body, human, animal or plant. In addition to providing a source of metabolic energy, however, dietary lipids provide a source of essential fatty acids, not

capable of being synthesized in the human body. Another beneficial function of dietary lipids is their ability to act as carriers of pre-formed fat-soluble vitamins (vitamins A, D, E and K) [6]. Less beneficial is their ability to also act as carriers of toxic fat-soluble components and their contribution of saturated and trans fatty acids and cholesterol.

Because essentially the same functions are performed in animal, plant and human, the lipids consumed from these sources will be found in similar structures to those inside the human body, mainly as TG particles coated with a solubilizing, stabilizing layer or multi-layer of membrane phospholipids. Breaking down the surrounding structures and releasing the lipid droplets from the cells, seed bodies or whatever locating matrix, will have a profound influence on our ability to digest the lipid and use its components efficiently and effectively.

In modern processed foods, fat (extracted from plant and animal sources) may also be incorporated within the food matrix in the form of emulsions. Examples of these processed foods include spreads, imitation creams, salad dressings, gravies, sauces, soups, confectionary products and chocolate. Here phospholipids can be used as emulsifiers, but monoacylglycerols and diacylglycerols also often feature as emulsifiers and stabilizers. More commonly, however, emulsions are protein-stabilized and this offers another layer of complexity to the digestion of these lipid-containing products. Lipids play a major part in determining the texture, flavour and taste profile of processed foods.

In this review, we focus on the physico-chemical properties of lipid emulsions and how the emulsion structure influences various steps involved in the digestibility of lipids.

## 2. Formation and stability of food emulsions

An emulsion may be defined as a dispersion of one immiscible liquid in another immiscible liquid in the form of droplets, the diameter of which is generally between 0.1 and 100  $\mu\text{m}$ . There is an interfacial layer between the two phases, which may be occupied by some surface-active agents. It is common practice to describe an emulsion as being oil-in-water (O/W) or water-in-oil (W/O), where the first phase mentioned is the dispersed phase and the second phase mentioned is the continuous phase. In some cases, the dispersed droplets themselves are emulsions, e.g. the dispersed phase now is the continuous phase for the droplets of the original continuous phase. Such emulsions are referred to as multiple emulsions (O/W/O or W/O/W). In this review, only O/W emulsions are considered. Detailed information about food emulsions can be found in a number of books [7–10].

In the food industry, O/W emulsions are prepared by high pressure homogenization, which causes disruption of the droplets by a combination of turbulence and intense shear flow; at the same time, the emulsifiers are adsorbed at the oil–water interface, forming a stabilizing layer at the droplet surface. Structurally, emulsifiers are amphiphilic molecules, possessing both hydrophobic and hydrophilic moieties. Consequently, emulsifiers tend to partition between the oil and water phases according to their relative solubilities in those phases – an emulsifier will usually be more soluble in one phase than in the other phase.

All emulsions are thermodynamically unstable and may break down into individual phases after certain time periods. Therefore, in practice, the kinetic stability of the emulsion is important. Emulsions may become unstable due to a number of different types of physical and chemical processes. The primary physical processes of instability are creaming, flocculation and coalescence, whereas chemical instability includes change in the composition of the emulsion droplets themselves, such as lipid oxidation and hydrolysis, or change in the composition of the interfacial layer.

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