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Potential impact of interfacial composition of proteins and polysaccharides stabilized emulsions on the modulation of lipolysis. The role of bile salts

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ABSTRACT

Important insights into the role of interfacial composition and structure in controlling the digestion of oil-water emulsions have been gained in the last decade. The driving interest relies on: i) the necessity of controlling the digestion of lipids to decrease or delay fat intake to address the obesity crisis existing worldwide and ii) assuring the bioaccessibility of bioactive emulsified lipids or hydrophobic bioactive compounds.

This article mainly reviews the relationship between the composition and structure of protein and polysaccharides stabilized emulsions and their susceptibility to in vitro lipolysis. The analysis concentrates on emulsions where (1) proteins or (2) polysaccharides are used as single emulsifiers, (3) emulsions stabilized by protein-polysaccharide conjugates, (4) protein-polysaccharide multilayer emulsions where the primary emulsion is formed by a protein, (5) protein-polysaccharide emulsions where proteins are the main emulsifiers and the polysaccharides perform as stabilizers.

The mechanisms involved in the control of the rate and extent of lipolysis are discussed with special attention given to the interactions between emulsions components and bile salts as a critical point for controlling lipids digestion.

1. Introduction

During the last decade, important insights into the role of interfacial composition and structure in controlling the digestion of oil-water emulsions have been gained. The driving interest relies on: **i)** the necessity of controlling the digestion of lipids to decrease or delay fat intake to address the obesity crisis existing worldwide and the implications for long-term chronic diseases, **ii)** assuring the bioaccessibility of bioactive emulsified lipids (e.g omega-3 fatty acids) or the delivery of hydrophobic bioactive compounds included in the core lipid.

A good overview of the biochemistry of human lipid digestion is given in previous reviews (Golding & Wooster, 2010; Singh, Ye, & Horne, 2009). In brief, lipids digestion starts in the stomach where about 20% of the lipolysis takes place by acid-stable gastric lipase. When the partially digested food moves from the stomach into the small intestine, it is mixed with bile salts (BS) and pancreatic secretions in the duodenum forming an emulsion stabilised by bio-surfactants. One of the key roles of BS is to prepare the surface of the fat to improve the access of lipolytic enzymes to the lipid substrates (Maldonado-Valderrama, Wilde, Macierzanka, & Mackie, 2011). Therefore, the lipids digestion occurs essentially in the small intestine where about 80% of the lipolysis takes place at the oil-water interface mediated by the pancreatic lipase-colipase complex, releasing the sn-2-monoacylglycerol and two free fatty acids (FFA) from triacylglycerols (Golding & Wooster, 2010). Lipolysis products are then incorporated into BS micelles to be transported in the aqueous medium and absorbed to the mucosa of the small intestine.

In vitro digestion studies are widely used with the aim of predicting the lipolysis of food emulsions in the digestive tract, because animal and human studies are costly and lengthy; moreover they are limited due to ethical considerations. Most of these studies are performed in static models where gastric and small intestinal digestion (GI) is mimicked in two consecutive steps (Minekus et al., 2014). In vitro models enable the prediction of emulsions changes during oral and GI digestion as well as the

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release of FFA. They allow the screening of comparatively large numbers of samples and/or conditions, studying the separate and combined effects of each stage of digestion (oral, gastric, small intestinal, large intestinal) on the release of FFA. Nevertheless, the diversity of existing models may hinder the comparison of results across studies. The employed models differ in the inclusion of one or more of the stages of digestion, digestion times, pH, the nature and concentration of digestive enzymes, concentrations of electrolytes and biosurfactants (bile acids, phospholipids). Finally, while most of the models are operated in static mode (with prefixed concentrations and volumes of digested materials, enzymes salts, etc), there are also a limited number of dynamic models that mimic the continuous changes of the physicochemical conditions to better simulate the human digestive tract (Alminger et al., 2014).

Despite the key role of interfaces in determining the behaviour of emulsions on digestion, there are few studies dealing with the effects of digestion conditions on interfacial structures. The research group from the University of Granada is pioneer in developing a specific device (the OCTOPUS) based on the subphase exchange technique, that allows to apply a customized interfacial in vitro digestion process in which the interfaces are subjected subsequently to conditions mimicking the passage through the gut (Maldonado-Valderrama, Holgado-Terriza, Torcello-Gomez, & Cabrerizo-Vilchez, 2013). It allows to measure in situ the evolution of the interfacial tension throughout the whole simulated GI transit and the mechanical properties of the interfacial layer (interfacial dilatational modulus) after each digestion stage (mouth, stomach and small intestines).

Several mechanisms can be involved in the effect that the composition and structure of emulsions and interfacial films surrounding the oil droplets have on lipids digestion (Fig. 1). The main mechanisms are summarized as follows:

- Flocculation and coalescence of oil droplets under gastroduodenal conditions that, by decreasing the interfacial area available for lipase/colipase adsorption, may retard lipolysis.
- Steric factors inhibiting the interfacial anchoring of lipase/colipase (big head groups protruding in the aqueous phase, thick interfacial films, rigidity of interfaces).
- Resistance of interfacial films to adsorption/displacement by BS.
- Accumulation at the interface of inhibitory lipolysis products (i.e, FFA, monoacylglycerols) due to a decrease in available BS and phospholipids that can be bound by adsorbed or unadsorbed emulsion components.
- Accumulation at the interface of inhibitory lipolysis products (i.e, fatty acids, monoacylglycerols) due to their binding to adsorbed emulsifiers.
- Inhibition of fatty acids uptake due to their binding to unadsorbed components.
- Decrease in available calcium by its binding to adsorbed or unadsorbed components. Calcium plays a critical role in the dynamics of fat digestion (Golding & Wooster, 2010).

This review will be focused mainly on the analysis of the relationship between the composition and structure of emulsions and the degree of lipolysis and less on the physico-chemical behaviour of emulsions during in vitro digestion. The analysis will concentrate on emulsions where (1) proteins or (2) polysaccharides are used as single emulsifiers, (3) emulsions stabilized by protein-polysaccharide conjugates, (4) protein-polysaccharide multilayer emulsions where the primary emulsion is formed by a protein, (5) protein-polysaccharide emulsions where proteins are the main emulsifiers and the polysaccharides perform as stabilizers.

The mechanisms involved in the control of the rate and extent of lipolysis of the different emulsions will be discussed. Special attention will be given to the interactions between emulsions components and BS as a critical point for controlling lipids digestion.

2. Protein stabilized emulsions

Proteins are known specifically for their surface activity, which

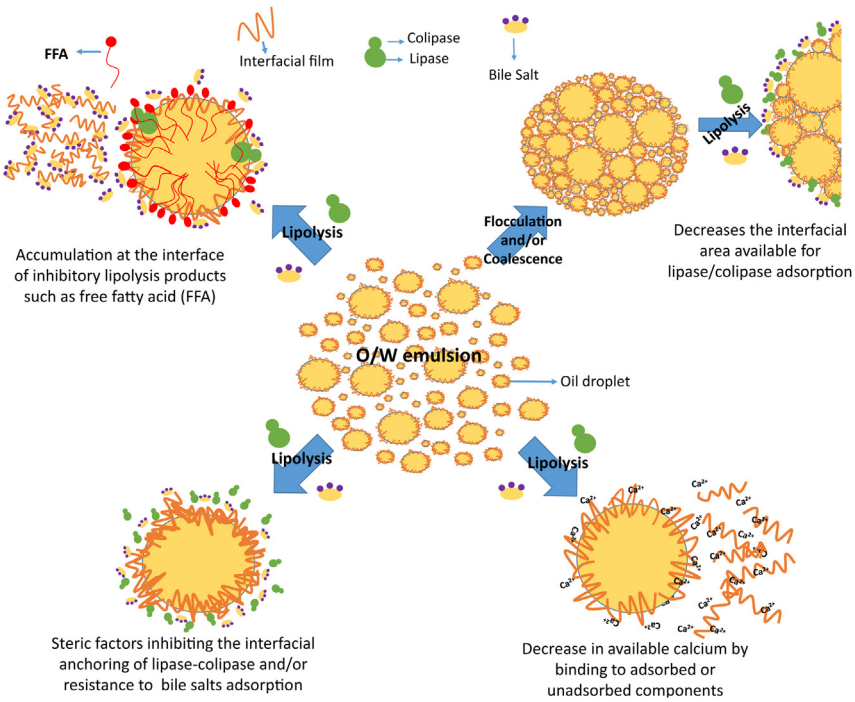

Fig. 1. Mechanisms involved in the modulation of lipolysis of emulsions.

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