G Model
FOOSTR 52 No. of Pages 11

ARTICLE IN PRESS

Food Structure xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Food Structure

journal homepage: www.elsevier.com/locate/foostr

Natural and processed milk and oil body emulsions: Bioavailability, bioaccessibility and functionality

Sophie Gallier[a], Dennis Acton[a], Manohar Garg[b], Harjinder Singh[c,*]

[a] Danone Nutricia Research, Uppsalalaan 12, Utrecht 3584 CT, The Netherlands
[b] Nutraceuticals Research Group, School of Biomedical Sciences & Pharmacy, University of Newcastle, Callaghan, NSW 2308, Australia
[c] Riddet Institute, Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand

A R T I C L E I N F O

Article history:
Received 8 February 2016
Received in revised form 9 June 2016
Accepted 18 July 2016
Available online xxx

Keywords:
Milk fat globule
Oil body
Digestion
Bioavailability
Bioaccessibility
Biomimetic

A B S T R A C T

A well-studied naturally-occurring lipid structure is the oil-in-water emulsion droplet. The interfacial quality and quantity of the oil droplets play a key role in the digestion in the gut and subsequent lipid uptake and may have longer term health consequences. Studies on natural droplets, the milk fat globules and the oil bodies, and the effect of processing on their structure and on their digestion are discussed. This article reviews how processing affects the structure of naturally-occurring oil droplets, how it impacts the lipid bioavailability and bioaccessibility, and highlights recent developments to mimic natural lipid emulsion functionality for infant nutrition.

Contents

1. Introduction

Lipids are essential macronutrients for the body; they are an important source of energy (9 kcal/g), constituents of cellular membranes and participate in several physiological processes. More than 95% of the dietary lipids are triglycerides. Other lipids include phospholipids, monoglycerides, diglycerides, free fatty acids, sterols and other minor lipids. Lipids in foods provide texture and flavour and act as carrier of liposoluble bioactive compounds. In natural foods such as milk, grains, nuts, eggs, meat and fish, lipids are present in the "free fat" form or in the form of complex structures, i.e. oil droplets, in which triglyceride particles are coated with a stabilising layer of emulsifiers (van Aken, 2010). Breaking down the surrounding structures and releasing the lipid droplets from the locating matrix, i.e. making lipids bioaccessible, have a profound influence on an individual's ability to digest the

* Corresponding author.
E-mail addresses: sophie.gallier@otago.ac.nz (S. Gallier), H.Singh@massey.ac.nz (H. Singh).

http://dx.doi.org/10.1016/j.foostr.2016.07.005
2213-3291/© 2016 Published by Elsevier Ltd.

lipid and use its components efficiently and effectively, i.e. the lipids being bioavailable.

Overconsumption of fat has been linked to the rise in obesity in Western countries. Therefore, it has been recommended that fat consumption should be limited to 30% of the total daily energy intake in adults (van Aken, 2010). Reduction of fat intake can be tackled by reduction of fat content in food, reduction of gastrointestinal lipolysis and controlled release of fat in the gastrointestinal tract to induce satiety. Ingestion of food activates hormonal and neural signals regulating digestion of food, gastric emptying and satiety. In the mouth, chewing of food allows breaking down of the food matrix into smaller particles and mixing with saliva. In the stomach compartment, digestion of fat and protein is initiated in acidic conditions. Further digestion takes place in the small intestine where the nutrients are absorbed.

The infancy period is an exceptional period during which up to 60% of energy intake comes from the natural fat in human milk or from lipids in infant milk formula. Human milk delivers lipids with specific functionalities such as essential fatty acids, phospholipids, and cholesterol that provide unique health benefits during early infancy that extend to long-lasting benefits. The qualitative aspects of dietary lipid fatty acid composition and lipid droplet structure in early life may contribute to the long-term health effects (Abrahamse et al., 2012).

In this review, we will focus on lipids present as natural oil droplets and how processing affects the structure of these droplets and their subsequent bioavailability and bioaccessibility. In addition, we present an innovative concept to mimic the natural milk fat globule structure and functionality for applications in infant nutrition.

2. Natural oil droplets

2.1. Mammalian milk lipids

Lipids in bovine and human milk are present as milk fat globules with a diameter ranging from less than 0.1 μm and up to 20 μm (Michalski, Ollivon, Briard, Leconte, & Lopez, 2004). The milk fat globule structure is similar in milks of other mammals, although the fat content varies greatly from less than 1% in rhinos' milk to 60% in seals' milk (Oftedal, 2012). A unique trilayer of phospholipids with specific proteins and cholesterol (Fig. 1), called the milk fat globule membrane (MFGM), stabilizes the fat globules in the milk serum phase (Heid & Keenan, 2005). This trilayer structure a is acquired during the secretion of the milk fat globules from the mammary gland cells (Heid & Keenan, 2005). The trilayer structure (for schematic see: Gallier, Laubscher, & Jiménez-Flores, 2014, Chp. 4; Lopez, Cauty, & Guyomarc'h, 2015; Vanderghem et al., 2011), from the inner side to the outer side of the membrane, is made of a monolayer of phospholipids and proteins (an electron dense layer), a bilayer of phospholipids, proteins and cholesterol, and a glycocalyx which is composed of the sugar residues on glycoproteins and glycolipids (Gallier et al., 2015; Heid & Keenan, 2005; Lopez et al., 2015). The thickness of the MFGM varies between 5 and 25 nm due to the protruding glycosylated molecules of the MFGM glycocalyx (Gallier et al., 2015; Heid & Keenan, 2005), which also provides steric repulsion between globules. Although the MFGM has a similar composition and structure across species, some differences have been observed. Human MFGM is highly glycosylated compared to bovine MFGM and other species (Buchheim, Welsch, Huston, & Patton, 1988). The MFGM phospholipid distribution is greatly influenced by the feed, season and breed of the cows (Michalski, 2009).

2.2. Plant-derived lipids

Seeds, grains and nuts contain unique storage lipid particles, called oil bodies or oleosomes (Beisson, Ferte, Bruley et al., 2001; Huang, 1996), found within the plant cell walls alongside protein bodies. Oil bodies have gained interest from the food, pharmaceutical and cosmetic industries and academic scientists as naturally-occurring delivery systems for bioactive compounds (Bonsegna et al., 2011; White, Fisk, Makkhun, & Gray, 2009). Oil bodies are often studied after extraction from the plant cell walls and resuspension in aqueous solution (Beisson, Ferte, Bruley et al., 2001; Gallier & Singh, 2012a; Gallier, Tate, & Singh, 2013; White et al., 2009). Their size varies according to their origin, from 0.6 μm in small oil seeds, such as sesame seeds, (Huang, 1996) and up to 5.8 μm in walnuts (Gallier, Tate et al., 2013). Oil bodies are spherical droplets composed of 94–98% of triglycerides and are stabilized by a 2–3 nm monolayer of phospholipids (0.6–2% of the dry weight) and embedded oil body-specific proteins (0.6–4% of the dry weight), mostly from the oleosin family (Beisson, Ferte, Bruley et al., 2001). The N-terminal and C-terminal domains of the

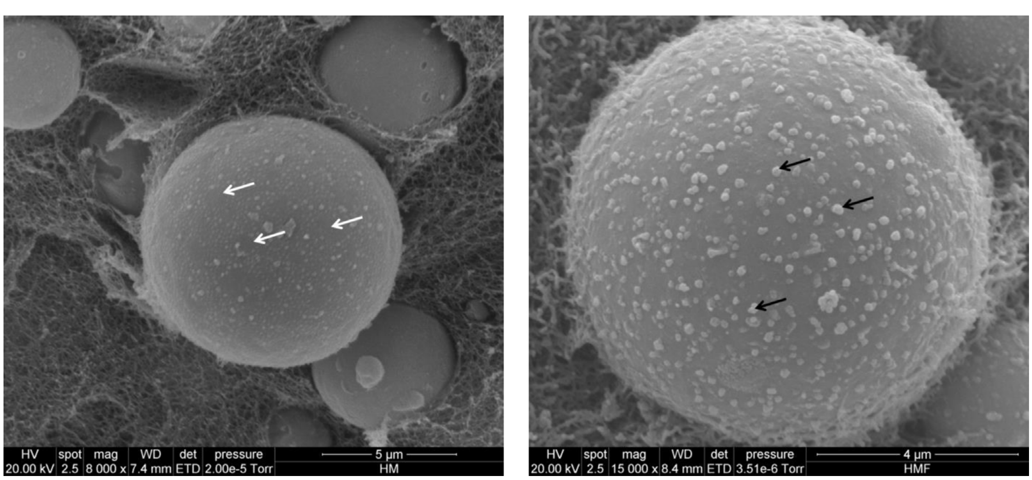

Fig. 1. Scanning electron microscopic images of milk fat globules from freshly expressed human milk (left) and from freshly expressed human milk incubated with filipin as in (Gallier et al., 2015) (right). The surrounding matrix is the agarose gel mixed with the milk samples before fixation with glutaraldehyde and post-fixation with osmium. White arrows indicate liquid-ordered domains, rich in sphingomyelin and cholesterol, seen as smooth domains, whereas the surrounding surface has a grainy texture likely due to the glycocalyx of the MFGM. This is another indication that glycosylated molecules partition preferentially in the liquid-disordered regions of the MFGM (Gallier et al., 2015; Lopez et al., 2015). Black arrows indicate the membrane deformation created by the filipin-cholesterol complexes (Gallier et al., 2015). Images taken by Dr Sophie Gallier for Danone Nutricia Research, Utrecht, The Netherlands.

Please cite this article in press as: S. Gallier, et al., Natural and processed milk and oil body emulsions: Bioavailability, bioaccessibility and functionality, food structure (2016), http://dx.doi.org/10.1016/j.foostr.2016.07.005