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# Bridging benchtop research and industrial processed foods: Structuring of model food emulsions

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ABSTRACT

Modern food formulation and processing are shaped by the consumer demands for cheaper, healthier, more palatable and convenient foods. In order to satisfy these ever-increasing demands, food scientists require comprehensive understanding of the structure-function relationship for effective, fit-for-purpose microstructural product design.

This review reports on the new approaches in the formulation and processing of model state-of-the-art emulsion-based food products, whose variety of physiochemical and sensory properties are created and controlled by their microstructure. Current know-how on the mechanisms that govern desired food behaviour with emphasis on their advantages, limitations and potential applications are reviewed on examples of model nano, duplex, Pickering, aerated and water-in-water emulsions.



## 1. Modern food science

Food and eating is central to our lives and goes beyond the biological need for energy, permeating all aspects of culture and society (Beer, 2001). The global, national and local food systems are complex and, despite feeding the world's population, are nevertheless inadequate in both the prevention of overnutrition (in estimated 2 billion adults and children) and undernourishment (in 1 billion) (Swinburn et al., 2011). The global food market faces new challenges arising from ongoing population growth, increased demand for animal protein food in Asia, growing causative relationship between diet and non-transmissible diseases (obesity, heart conditions and some types of cancer) and competition for land and water from other crops, such as biofuels (Copeland, Blazek, Salman, & Chiming Tang, 2009). As a result, the traditional aspects of food quality such as appearance, safety and taste are no longer satisfactory, and are now extended by cultural, ethical and environmental qualities (Beer, 2001). The contemporary customer expects to know how the food was produced (e.g. free range animals, hormone- and antibiotics-free, fair trade) and where, as food regulations vary across the globe regarding, for instance, additives (e.g. preservatives, sweeteners, colours, flavours etc.) and new technologies (e.g. GMO, nanotechnology, animal cloning etc., Bánáti, 2011). A well-supplied modern marketplace induces fierce competition between food manufacturers who produce, process and deliver food products according to consumer-tailored specifications (Aguilera & Lillford, 2008).

Obesity has now reached a pandemic scale. Once linked to a "*Western society diet*" in developed countries, it is now widespread in the middle- and low-income developing countries (WHO, 2012a). For instance, around 35 million overweight children live in developing countries, compared with 8 million in developed countries (WHO, 2012b). With

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health and wellness as one of the main factors driving the modern food industry, an increasing number of consumers are telling food manufacturers that they wish to eat healthy, nutritionally balanced food, often with additional, personalised and specific contribution to health (Aguilera, 2006). It is essential that such foods match all of the taste and convenience of currently manufactured unhealthy food products and are cheap, in order to keep up with the population growth. These ever increasing demands call for significant improvements in process efficiency and a fit-for-purpose product quality, which can be achieved through comprehensive knowledge of food structure and specific functions, which individual food components exhibit, either alone or as a part of a multiphase, multicomponent food matrix. Only by understanding mechanisms underpinning food structure formation (during food manufacture and prior-eating preparation) and its breakdown (during eating and digestion), will food engineers be able to (re)design microstructures that are both meeting consumer expectations and are stable enough to withstand changes during the shelf-life of the product.

## 2. Structure-functions relationship

There are some examples of a clear link between structural features and a specific behaviour of a food product. For instance, ice crystal size influences the smoothness of the ice cream, the size of surface pores determines the colour of a freeze-dried coffee and the destruction of the cell wall in tomatoes have been related to a better bioavailability of nutrients (Aguilera & Lillford, 2008). Studying food microstructure is nevertheless challenging, mainly due to the inherent complexity of food products (Dickinson, 2010), which may contain many different constituents, whose functions are still not completely understood. For example, there is a large textural difference between skimmed milk and milk with 1% fat. However, it is not yet clear how fat globules can cause such a significant effect at such a low concentration (Kokini & van Aken, 2006). Owing to hierarchical structures in food, with variety of length-scales and time-scales (Fischer & Windhab, 2011), another major challenge in finding structure-function relationship remains in probing the structure at the appropriate scale (Aguilera & Lillford, 2008) and correlating it with the sensory perception of the consumed food material. Therefore, a novel approach has to be applied where the study of food microstructure is combined with mechanical properties, oral physiology and sensory evaluation (Çakir et al., 2012; Kokini & van Aken, 2006; de Wijk, Janssen, & Prinz, 2011; Singh, Ye, & Horne, 2009). The multidisciplinary approach in studying and structuring food with a required behaviour needs to be complemented by an understanding of food digestion, as emphasised by Singh et al. (2009), Golding and Wooster (2010) and McClements and Li (2010). Golding and Wooster (2010) review the progress in understanding how integrated emulsion properties (i.e. particle size, colloidal stability, interface, lipid type and structure) of a model food system impact lipid digestion and metabolism. The authors identify that transferring this knowledge to invariably more complex and multicomponent real foods remains a key challenge. Recent work on the microstructural changes in the gastrointestinal environment of hydrocolloids (Gidley, 2013), biopolymer complexes (Li & McClements, 2013) lipid emulsions stabilised with different emulsifiers (Hur, Decker, & McClements, 2009), lipid emulsions with salt (Hur, Joo, Lim, Decker, & McClements, 2011), heteroaggregated low fat systems (Simo, Mao, Tokle, Decker, & McClements, 2012), nanoemulsions (Salvia-Trujillo, Qian, Martín-Belloso, & McClements, 2013) and nanoparticles (McClements, 2013) provide information that may be used in formulating the delivery systems that control the digestion of specific ingredients and therefore allow for designing a desired physiological response.

Texture of food is a multi-parameter quality that originates from its microstructure and is perceived through many senses (vision, hearing, touch and kinesthetic) (Çakir et al., 2012). Textural perception of low-viscosity model food emulsions has been investigated by Vingerhoeds, de Wijk, Zoet, Nixdorf, and van Aken (2008) by using a qualified sensory panel. Fat-related attributes could be effectively enhanced by addition of fat dispersed phase and substitution of the sunflower oil with crystalline fat that melts at body temperature. Employing a trained sensory panel, although most effective in quantifying the sensory perception of certain structures is, however, highly modulated by the individual attributes of the panellist (mood and environment), but also costly and time-consuming (van Aken, Vingerhoeds, & de Wijk, 2011). Consequently, there is a need to develop suitable techniques to study structure-function relationship in food products (Aguilera, Stanley, & Baker, 2000), whose perceived properties, unlike unambiguously defined and measured traditional engineering materials (Aguilera & Lillford, 2008), are largely predisposed by individual consumer preferences.

### 2.1. *Rheology*

One of the methods to characterise food structure and its implicit function(s) (e.g. texture) is rheology. It describes flow behaviour of food products during production and preparation (in the kitchen), but also its impact on food perception and digestion (in the mouth, stomach and intestine) by both flow properties and triggering flavour and aroma release (Fischer & Windhab, 2011). Due to the intricate rheological behaviour of many food products, any modification in the product composition (e.g. to increase food stability) may alter its texture perception and compromise food palatability. Therefore, improving nutritional value of the product, either by fat reduction or by the incorporation of a desired nutrient (e.g. vitamin), is not as simple as removing or adding a portion of the respective ingredient. For example, attempts to reduce the high-energy dense cocoa and milk fat in chocolate resulted in a considerable increase in the product viscosity during manufacturing (Fischer & Windhab, 2011) and undesirable textural behaviour (Do, Vieira, Hergreaves, Mitchell, & Wolf, 2011).

In the search for a fat reduction strategy, the in-mouth textural perception of a model liquid emulsion (oil in continuous water phase) has been studied by van Aken et al. (2011). When increasing the dispersed phase (oil) volume, higher viscosity samples were produced, which resulted in thick and creamy *mouthfeel*. The authors implied that a similar effect (although for relatively high viscosity products only) can