
1 Introduction to Food Formulation Engineering

J.E. Norton, P.J. Fryer and I.T. Norton

Centre for Formulation Engineering, University of Birmingham, UK

1.1 INTRODUCTION

Food products are often structurally complex. This structure, or microstructure, determines the foods flavour (as a result of tastant or aroma release), its texture and mouthfeel, and the eating pleasure derived from its consumption, in addition to the efficiency of uptake during digestion, the bioavailability of active compounds, and the effect it has on appetite and satiety. With the health issues of the modern age, including the prevalence of obesity, food research is often heavily focused on fat reduction, or methods of reducing the uptake of fat or slowing digestion, whilst maintaining sensory appeal and palatability.

Thus, a combination of understanding of material chemistry and material science is needed, together with an understanding of how processing affects food structure, the science behind food consumption, from oral processing through to digestion, and the impact that food formulation engineering can have on liking, sensory perception, digestion, targeted delivery or appetite. This book aims to provide the reader with detailed reviews of the literature in these areas.

The book is separated into three main sections: 1. Designing Structured Foods, 2. Structure–Human Interaction and 3. Food Structure and the Consumer. In the first part of the book we will consider how basic materials can be used to formulate complex food systems, with specific structures, desirable sensory attributes and health benefits. In the second part we will consider structure–human interaction, and how foods can be designed to get the greatest positive impact (in terms of oral processing and/or digestion) when producing healthier, more convenient, and/or more environmentally friendly products. In the third part we will consider psychology, and the impact that food can have both on liking and acceptability, and appetite and satiety.

1.2 THE BOOK

1.2.1 Designing structured foods

In the first part of this book we will consider the design of foods, and the use of complex structures. We will consider how basic materials (i.e. proteins, polysaccharides and hydrocolloids) can be used to structure foods. We will also consider the use of emulsions (the most common use of fats in foods). This section contains four chapters:

Chapter 2 (Harris and Foegeding) considers the use of proteins in foods, by building food structures that provide desirable sensory (e.g. flavour, taste or texture) and health (e.g. nutrition and bioavailability) attributes. Proteins function by providing amino acids for protein synthesis and energy, providing bioactive peptides, and are also essential for the formation and stabilisation of food structures. During food processing, changes in the protein structure can occur, including denaturation or aggregation, racemisation, or covalent modification of amino acids (e.g. Maillard browning). Proteins are important in many colloidal structures, including sols, emulsions, foams and gels, and can contribute to the stability of these systems by adsorbing at the interface. Proteins are essential for health, but also have a positive impact on satiety, as a result of both sensory cues (e.g. thickness/viscosity or savoury taste) and the macronutrient itself. The goal should be to combine food science and nutrition, to produce “nutritious and delicious” protein-rich foods that are highly nutritious and functional, but also highly palatable and satiating, that consumers would choose to eat.

Chapter 3 (Foster) discusses the use of plant cell wall material (PCWM), a material that is not usually utilised, which may have significant and novel use in food products. PCWM could be used as an alternative to refined polymers, which are often accompanied by tight specifications. It can be split into “inner” fibres (that are able to modify texture) and “outer” fibres (which are a source of high insoluble dietary fibre). Understanding of the processing steps (i.e. enzymatic, thermal, mechanical and chemical), and their effect on the polymers within the PCWM can allow for controlled and reproducible food production. This, in turn, requires an understanding of PCWM at a material and molecular level, in order to redesign or optimise processing. The rheological properties of PCWM are similar to hydrocolloid gel networks, where particle–particle interactions and particle size distributions both determine rheological structure. Furthermore, these materials could be used as surface-active materials for emulsion and foam stabilisation (i.e. as “natural” surfactants). Particularly,

β -glucans, are becoming well characterised, and could be used for fat replacement, or as emulsifiers. β -glucans are interesting because of their functionality (ability to decrease serum cholesterol levels). In taking such an approach, the greater availability of molecules retained within natural fibres can be used to provide natural and healthy food ingredients.

Chapter 4 (Wolf) details the use of hydrocolloids (water soluble gums) in food structures, to impart specific flow and textural properties, either as water continuous foods, or within the aqueous phase of emulsions. Phase separation in hydrocolloid mixtures can result in water-in-water emulsions, which prior to gelation behave like conventional emulsions (similar in size to droplets within classical food emulsions). By controlling shear and temperature at the time of gelation, sheared gels, or fluid gels, can be produced. Gel suspensions, or filled gels, can also be produced in phase separating hydrocolloid mixtures, where one is gelling, to produce systems where the shape of the particle can be controlled. Similarly, when a gelling hydrocolloid is added to the aqueous phase of water-in-oil emulsions, shaped particles can be produced, which can be used in lipid-based food products. Finally, microfluidics (e.g. rotating membrane processing) has also been used to produce monodispersed gel particles. These phenomena can be utilised to influence food structure, to impart specific flow properties, textures or appearances, in order to produce novel food systems.

The final chapter in this section, **Chapter 5** (Pawlik, Fryer and Norton), considers the use of emulsions, either in their simple (oil-in-water, or water-in-oil) or more complex forms (duplex emulsions: water-in-oil-in-water, or oil-in-water-in-oil) in foods. Pickering emulsions are stabilised by particles that are thought to be irreversibly adsorbed to the interface. Surface-active crystalline monoglycerides may also stabilise emulsions in a similar way, and by modifying temperature and inducing melting, molecules from the internal droplet may be released. Nano-emulsions, that have a droplet size of less than 200 nm, have many advantages over conventional emulsions, including being transparent and extremely stable against aggregation and gravitational separation. Duplex, or double, emulsions, which are produced in two emulsification steps, also have many benefits, including the advantage of being able to encapsulate ingredients into the internal droplets, which could then be delivered in a controlled way on consumption. Tri-phasic emulsions are aerated systems that contain both oil and air in an aqueous continuous phase, and water-in-water emulsions, which as mentioned above are a result of the phase separation of incompatible protein or polysaccharide solutions, may both be effective methods for fat reduction in foods.

1.2.2 Structure–human interaction

In the second section of the book we consider the interaction that food has with the people consuming it. This involves understanding of the physics of eating, the perception and manipulation of texture, the release of tastant and aroma compounds, lipid digestion, and the encapsulation and targeted delivery of compounds. This section is split into six chapters:

Chapter 6 (Lillford) considers the physics of eating, particularly related to the human masticatory process. This involves chewing (size reduction via mechanical forces, using teeth), mixing (using the tongue), lubrication and dilution (via the addition of saliva), breakdown and reassembly, and the swallowing of a bolus. The act of eating is complex, because the geometry of the device is complex, there is feedback and feedforward regulation of the actions involved, and there is huge variability between individuals. The foods that we consume (natural or processed), also vary considerably, in terms of structure, mechanical properties, such as work to fracture (and subsequent sound emission), particle size, moisture content, fat content, viscosity, phase volume of air and the presence of ice or fat crystals. These properties affect masticatory processing and food breakdown, and can be related to perceived hardness, juiciness, crispness, moistness, smoothness, creaminess, greasiness and so on, but also enjoyment and pleasure. Understanding the physics of eating is important if we are to appreciate the enjoyment associated with particular foods, and if we are to generate new foods that are pleasurable to eat.

Chapter 7 (Le Révérend, Gouseti and Bakalis) focuses on the interaction between food and the oral “machinery”. It begins by describing the current understanding of oral processing, and its relationship with sensory perception (particularly related to our perception of taste and texture). It also discusses our ability to monitor and model oral processing. Both simulating and modeling oral processing can result in the analysis, and prediction, of food transformations occurring during consumption, which in turn could be related to sensory perception. Simulation could be achieved using rheology (to gain an understanding of bulk viscosity), texture analysis, or tribology (which is the measurement of friction and lubrication), which have been related to thickness, viscosity, hardness, or creaminess, for example. Mouth models have also been investigated, that apply mechanical forces to simulate mastication, in the presence of artificial saliva. The interaction between foods and the oral cavity is discussed, particularly the effect that saliva has on emulsion breakdown, and subsequent sensory perception, in addition to the effect of mucoadhesion on perception. An understanding of the pro-

cesses occurring during consumption could allow food products to be designed that have particular textures or tastes, as a result of breakdown partners and their interaction with the oral cavity.

Chapter 8 (Mills) discusses approaches to salt reduction in foods. Whilst salt is essential for human health, excessive amounts can be detrimental, resulting in hypertension and stroke. Salt is one of the five tastes, which relies on the sodium ion component of sodium chloride. Saltiness perception is affected by factors such as the viscosity of the food matrix (as a result of mixing ability and contact with the oral surfaces), the homogeneity of salt distribution, and the release profile. A number of methods to achieve a significant reduction of salt in foods are discussed, including the gradual reduction of sodium, substitution with other salts or glutamates, enhancement with spices or flavourings, or the use of complex microstructures (such as the inhomogeneous distribution of salt in foods, or the use of water-in-oil-in-water emulsions). These technologies could also be combined, in order to produce food products that maintain the sensory appeal and palatability of the saltier foods that consumers have become accustomed to, but that contain less salt, thus having less of a negative impact on health.

Chapter 9 (Linthorpe) highlights the importance of understanding volatile aroma release in foods. Aroma molecules vary according to water and fat solubility and intrinsic volatility, both of which affect the way they partition between different phases of foods, and the efficiency of transfer to the breath, so that they can be detected by the nose. The viscosity of the food can affect the delivery of aroma compounds to the nose, although this is also affected by the type of volatile, and individuals' eating styles. In gelled systems, gel strength could also affect intensity of aroma perception and release profile. Interestingly, inhomogeneous distribution of aroma compounds did not affect intensity or timing of flavour delivery, as was shown in the case of salt. Instead, flavours could be encapsulated, which can protect flavour compounds and alter the release profile. Different trigger mechanisms could also be utilised, such as hydrolysis by enzymes, mechanical fracture and melting. Understanding flavour perception is important when manipulating food structure (either when simply changing aspects of food itself, or when specifically trying to modify flavour delivery), and should be considered when creating new generations of food products.

Chapter 10 (Golding) considers lipid digestion. The immiscibility of lipids with the aqueous digestive environment means that lipid digestion is achieved by the adsorption of enzymes at the oil–water interface, so is affected by the interfacial area and thus the availability of binding

sites. As such, having a colloidal state during gastrointestinal (GI) transit is necessary for fat digestion. Oral processing is the first step in lipid digestion, ensuring that all ingested fat is delivered to the stomach in an emulsified state, and involves mechanical forces, secretion of mucous (containing surface-active compounds that lower surface tension and provide surface elasticity), production of enzymes and thermal normalisation to 37 °C. The conditions of both the stomach (i.e. acidic pH, release of gastric amylase and lipase, gastric motility and mixing, and temperature) and the intestine (e.g. bile salts) affect emulsion structure and stability. The detection of fat results in the secretion of hormones, which slow the rate of gastric emptying (ensuring full digestion and uptake), and suppress hunger. The structure of fats during digestion can be affected by the presence of proteins, emulsifiers and crystalline fat, so that emulsions could be designed to have specific digestive behaviours, such as reduction in uptake or improved delivery of bioactives.

The final chapter in this section, **Chapter 11** (Spyropoulos and Nowak), considers the potential for the use of hydrocolloid formulations in novel foods, specifically designed to impact on the functions in the GI tract. Hydrocolloid-based delivery systems for the encapsulation and targeted delivery of nutrients (e.g. vitamins), microbial supplements (probiotics), dietary fibres (prebiotics), lipids or therapeutic species (e.g. drugs) are discussed. The system can be designed for the protection of encapsulated material, and for the delivery to specific parts of the GI tract (e.g. induced by pH). Hydrocolloids themselves, and/or hydrocolloid-based structures, can also have an effect on physical functions in the GI tract. They can affect gastrointestinal transit time, as a result of increased viscosity or gel formation (as a result of acidic or ionic gelation), and absorption rates (as a result of enzymatic activity). Finally, hydrocolloids may have additional benefits, such as the ability to aid in mucosa healing, reduce post-prandial blood glucose levels, reduce cholesterol absorption, and have the ability to bind mutagens and heavy metals present within the intestine, thus reducing carcinogenic effects. There is clearly a potential for the use of hydrocolloids in the fabrication of novel functional food, which could impart significant health benefits through their action at specific parts of the GI tract.

1.2.3 Food structure and the consumer

In the final section of this book we consider psychology, both in terms of liking and the relationship with health-related technologies, and the

impact that either different macronutrients and/or food structure can have on satiety and appetite. This section is split into two chapters:

Chapter 12 (Norton) explores consumer acceptability, which encompasses liking, palatability, perceived quality, choice and purchase behaviour, and consumption. The sensory characteristics of the food are incredibly important for acceptability, but situational/environmental (e.g. the physical surroundings, or who we are eating with) and cognitive (e.g. expectations) influences also have an impact on liking and acceptability. The chapter also describes the different direct and indirect methods used by researchers for measuring acceptability, including hedonic measures (e.g. liking questions), experimental auctions, eye-tracking and brain imaging. The chapter also considers some of the current food trends (fat reduction, salt reduction, self-structuring and satiety, and functional or personalised foods), bringing together literature around physical science, sensory science and psychology, in order to understand the impact that these findings have on food engineering, and the design of food structures with specific health benefits. It is important to consider consumer acceptability, as not only does this ultimately determine the success of food products, but food products can only have benefits for health if they are chosen, liked and consumed.

Chapter 13 (Harrold and Halford) discusses within-meal satiation (that determines meal duration and size, and terminates eating) and post-meal satiety (determines the length of post-meal interval), and the effect that macronutrient composition and food structure have on short-term appetite regulation. The satiety cascade highlights the sensory and cognitive factors that contribute to eating behaviour, and the properties of food that influence appetite control. Gut hormones cholecystokinin (CCK), glucagon-like-peptide-1 (GLP-1), peptide YY (PYY) and ghrelin all influence appetite regulation, as does the central nervous system and the brain. There are a number of methods for measuring appetite, including pre-load designs and ad libitum intake, and measures of subjective appetite sensations. The chapter also discusses the satiating effect that different macronutrients (protein, fibre or lipids) have, and also the impact food structure (viscosity, gelation, encapsulation or emulsification) can have on satiety signals and appetite. However, the authors highlight the impact that a combined approach could have on appetite, whereby food structure could boost the effect of nutritional manipulations and enhance satiety, enabling consumers to restrict their intake, resulting in weight loss and prevention of weight regain.

1.3 CONCLUSION

As this book should highlight, a multidisciplinary approach, that utilises information gathered from many disciplines (including material chemistry, chemical engineering, biology, sensory science and psychology), should allow scientists to tackle some of the food-related issues of the modern age. This should allow food products to be produced that use basic materials (e.g. proteins, polysaccharides or hydrocolloids) to structure foods, or the design of food microstructures (e.g. emulsions) in intelligent ways that provide health benefits, such as increased satiety, reduction in the uptake of fats or salt, or the bioavailability of active compounds. These foods should also taste good, delivering flavour and tastants effectively, and having textures that consumers desire (such as creaminess). In order to fully understand how these foods perform, knowledge is required of the physics of eating (including of mastication and food breakdown), the interaction with saliva and the release profiles of both aroma compounds and tastants. The effect that food structure has on digestion, and uptake of both macro- and micronutrients, is also important, in order to produce foods that have limited uptake (e.g. fat-containing foods), or increased uptake (e.g. active compounds). An understanding of consumer acceptability is also required, in order to ensure that foods with health benefits are liked and repeatedly consumed, as is an understanding of within-meal satiety and post-meal satiety, in order to produce foods that can regulate appetite. With extensive understanding of all these areas, scientists can begin to think of creative ways to produce foods that offer all of the above-mentioned benefits.