Structure engineering in Foods

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ABSTRACT

With the concept “structure engineering” we mean knowledge about how structures can be generated by processing in combination with choice of ingredients. The term ”structure engineering” also means that we need to know how to tailor-make structures in order to achieve the desired rheological properties.

INTRODUCTION

Structure engineering is a challenging multidisciplinary field of research. There is a need for knowledge about structure formation combined with technology for microstructure processing that can lead to new developments within the food and pharmaceutical industry.

From an industrial point of view the focus on structure opens up new routes for process and product development. Knowledge about process induced structure formation can be used for formulations and process designs. The needs from the market to develop products with the desired texture and quality properties can be linked to very early stages of structure development.

From a scientific point of view structure engineering is multidisciplinary in nature and we are only in the beginning of an intriguing field of research. Today we are developing research tools to address a higher degree of complexity and we can therefore apply basic research concepts on complex systems of relevance for industrially processed food products.

For dairy products the field of structure engineering is especially important. Intense activities are going on both with regard to fundamental work on model systems and within product and process development in industry. Long tradition and craftsmanship have given us a wide range of structured products such as cheese, butter, yoghurt, cream etc. New demands on low fat products and new processing techniques have added structure engineering knowledge to the traditional routes of dairy food production. Today the dairy industry is in the leading front of food structure processing.

The structures of dairy ingredients are very sensitive to processing. The structure and related properties can therefore easily be manipulated by temperature treatments, flow conditions and the presence of other components. This paper is an overview of work performed in our laboratory on structure engineering of dairy products and model systems. The effect of processing conditions on structure and rheological properties will be demonstrated. New techniques make it possible to follow the structure formation and structure break-down directly under the microscope. For the understanding of complex food structures we need information over length scales from the nanometer to the micrometer regimes.

MODEL SYSTEMS

Simple whey protein systems

The main whey protein ß-lactoglobulin is suitable for model studies, because it is extremely sensitive to processing parameters such as heating rates, shear and pressure as well as to factors such as pH, salt composition, other biopolymers and food constituents.

Completely different types of gel structures can be formed depending on the state of aggregation[1]. Coarsely aggregated gel structures are formed in isoelectric region, around pH 4-6. The pH range of this region can vary depending on the presence of salts, other components and the prehistory of the sample etc. The aggregated form of whey proteins is very suitable for structure engineering studies not only because its process sensitivity, but also because the structure has features in common with dairy products such as yoghurts, cream cheeses and some types of spreads.

The heating rate during aggregation and gel formation of ß-lactoglobulin gels has a pronounced influence both on the pore and the particle size [2]. The pore diameter increased from ~20 to ~100 µm, when the heating rate was decreased from 12 to 1°C/min for 10% ß-lactoglobulin gels at pH 5.3. Studies of the texture of whey protein gels formed at different heating rates also showed that differences in pore and particle size of the gels had significant effects on the sensory perception of firmness and graininess of the gel structure[3]. The particle size of the aggregates composing the network was in the range of 0.8-1.4 µm in diameter. This means that we are very sensitive to effects of small structure changes on the micrometer scale, when we eat semisolid foods like gels.

During food production ingredients are being subjected to flow and are being sheared during mixing and transportation. This will affect the microstructure of the final product. Therefore, the scale of a process line, the geometries of tubes, the flow rate etc will affect the final microstructure. Whey proteins are very sensitive to shear and the prehistory of the samples can have drastic effects on the final structure and rheological properties[4]. This is illustrated in figure 1.

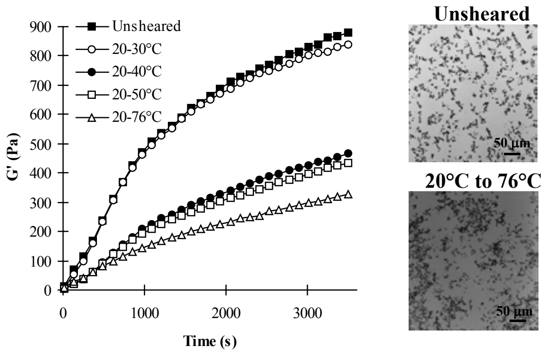

Figure 1. Effect of shearing in different heating regimes on the storage modulus of whey protein gels[4]

In this experiment the solutions were sheared during heating and the figure shows the effect of shear on the final storage modulus and the microstructure of the gels. It is interesting to note that that shear during heating from 20 to 30°C has no effect, whereas shearing in the temperature range 20 to 40°C has a dramatic effect on the storage modulus of the gel formed at 90°. The light micrographs show shear induced aggregation during heating.

Mixed whey protein gel systems

Model systems of simple protein systems are often being used in research. Addition of other ingredients quickly makes the systems very complex, which is one reason for the difficulties to understand real food systems. Dramatic changes can be obtained just by adding a second component. Mixed biopolymer systems have been a subject for intense research during the last decade. One reason is that phase separation in combination with gel formation makes it possible to modify the morphology and related rheological properties. The possibilities to obtain different types of structures from mixed biopolymers can also be achieved by the choice of process.

Generally, the order of gel formation determines the morphology. This has been demonstrated in our laboratory by studies of whey protein/gelatin mixtures[5]. On conventional temperature induced gel formation, whey protein form a gel network on heating and gelatin sets on cooling in the pores of the whey protein network. In this way, a bicontinuous structure is formed, where both gel structures contributes to the rheological behaviour.

Whey proteins can also form gels by high pressure treatment, which is not the case of gelatin. Instead, we let the gelatin gel set prior to high pressure treatment and the why protein gelled during high pressure treatment in the gelatin network. In this way, a gelatin continuous network was formed with whey protein inclusions. We could also let the two components gel at the same time by a combination of temperature and high pressure treatment. Also in this case, a gelatin continuous structure was formed.

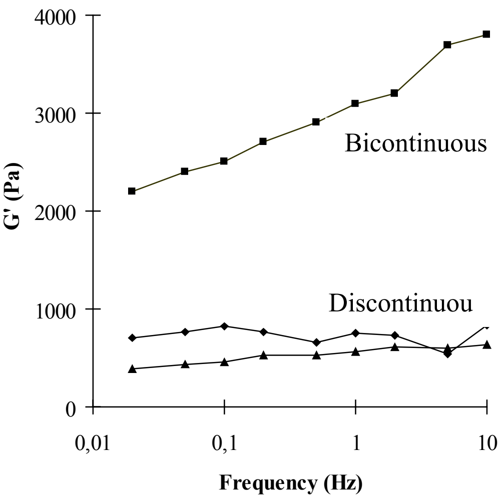

Figure 2. Frequency sweeps of 12%whey protein/ 3%gelatin mixed gels at pH5.4 [5]

The bicontinuous structure gives rise to a higher storage modulus and different frequency dependence than the gelatin continuous structures. Even more important is the difference in melting behaviour. The gelatin continuous structures melt around 30°C like pure gelatin, whereas the bicontinuous structure does not melt with increased temperature due to the whey protein network. Thus the different structures have different fields of application.

Dramatic changes can be also obtained just by adding a second component to whey protein system. If whey protein is mixed with non gelling amylopectin, the whey protein network structure is changed as illustrated below [6].

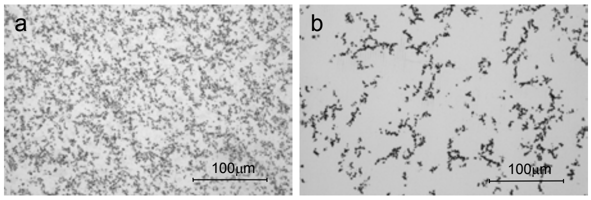

Figure 4. 6% whey protein without (a) and with 2% amylopectin [6]

The gel structure is influenced not only by the amount of added amylopectin but also by its molecular weight. The rheological response is complex. As long as the connectivity of the gel network is maintained, the gel strength is increased, but at a certain point the loss of connectivity leads to a weakened gel structure[7]. Recent developments of dynamic measurements makes it possible to follow both structure formation and the structure breakdown directly under the confocal laser scanning microscope[7]. By these techniques we can establish new insights in the mechanisms of aggregation and phase separation. It also makes it possible to monitor crack propagation during fracture in different types of gel structures.

FOOD PRODUCTS

The knowledge obtained from studies of model whey protein systems is important for the understanding of complex food products. Dairy products like yoghurts and cheeses are based on a gel structure in combination with a fat emulsion structure. As illustrated by the SEM micrographs below, the yoghurt structure and the aggregated whey protein structure have a similar length scale and the yoghurt can be studied by a similar approach as the model whey protein system.

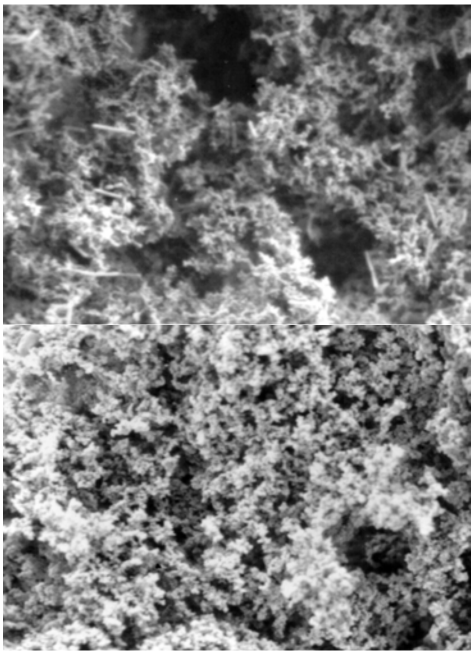

Figure 5. SEM micrographs of yoghurt (top) and a particulate whey protein gel (bottom)[8]

In real food products the interplay between components are even more complex than in model systems and variations in the processing conditions can have a major impact on the final product properties. Therefore a wide variety of textures can be achieved for products such as yoghurts and cheeses. New demands for healthier foods have enhanced the need for structure engineering. Today, products are available on the market with a creamy texture and a low fat content.

There is an inbuilt conflict in the design of dairy products with a desirable mouthfeel. They should be stable during production and storage but they should melt and break easily in the mouth during consumption.

For the new generation of health foods with active functional nutrients we need to design structures that preserve the nutritional compounds during handling and storage and facilitate release during consumption. This is an area, where new concepts such as micro-machining and nanotechnologies for particle sizing and interfacial structuring will open up new possibilities for structure engineering.

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