FOOD MICROSTRUCTURE

Aguilera, José M.

Department of Chemical and Bioprocessing Engineering, Universidad Católica de Chile ,Chile

Contents

Summary

Food microstructure recognizes that foods are highly structured and heterogeneous materials composed of architectural elements ranging from the submicron level to those seen with the naked eye. More important, the types of such structural units and their interactions are decisive in the perception of many sensorial properties, the way that foods perform as engineering materials, and how they break down during storage and mastication. The structure-property relationships of foods describe the way in which physicochemical, functional, and technological properties of foods relate to their structure.

This article revises different microscopy techniques used to characterize food microstructure from the conventional light microscope to advanced techniques such as electron, confocal laser scanning, and atomic force microscopy. Examples are presented on the role of microstructure in ice cream, frozen and extruded foods, and new fabricated products such as low-calorie spreads. Food microstructure is likely to play a

decisive role in the future, as the food industry advances towards designed foods and improved or new products.

1. Introduction

Modern food technology can be defined as a controlled effort to preserve, transform, create, or destroy food structure. In 1993, food microstructure was defined as the spatial arrangement of elements in a food and their interactions, stressing that visual observation is important in the analysis of the formed structure. Several structural elements were identified in foods: water and oil droplets, gas cells, fat crystals, strands, granules, micelles, and interfaces. Another definition of food microstructure comes from a discussion paper from 1980, which states: "...(structure) is the organization of a number of similar or dissimilar elements, their binding into a unit, and the interrelationship between the individual elements and their groupings". In both definitions, two aspects are emphasized as crucial: the organization of elements and their interactions. Thus, the microstructure of a food can only be understood when its elements (solid, liquid, and gaseous) and resulting architecture are considered in a dynamic and interrelated condition.

Chemical components play significant roles in the structure, stability, and nutritional value of a food. Macromolecules (polysaccharides, proteins, and lipids) form assemblies in nature that embedded or intertwined with other phases give rise to the native structure of raw food materials. Humankind has learned to break down natural structures and produce purified ingredients. Thus, a primary food industry extracts, refines, and converts agricultural raw materials from their native structure into functional molecules (sugars, oils, and fats) and macromolecules (polysaccharides and proteins), which are the basic building blocks for a high-volume food industry that mixes and reassembles them into products (Figure 1).
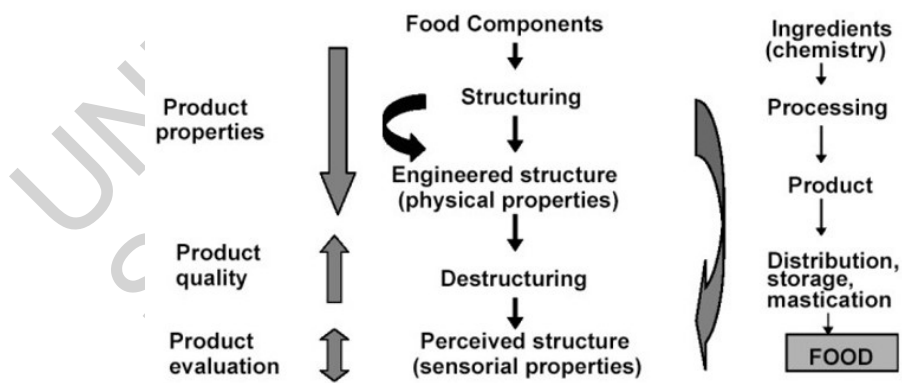
Figure 1. The microstructural approach.
[From: Aguilera J.M. and Stanley D.W. (1999). *Microstructural Principles of Food Processing and Engineering,* 2nd Edition. Maryland: Aspen Publishing Co.]

Processing, or the controlled incorporation of materials and energy into a food, is really a restructuring or reassembling operation, whether desired or not. As a result, an "engineered" structure is obtained, which has probably undergone modifications at four

structural levels: molecular, nanostructural, microstructural, and macrostructural. It has been suggested that transformations leading to the engineered structure contribute to the novelty of the product. The term "engineered structure" refers first to the controlled transformation of a native structure to any desirable structure worthy of consumption as a recognizable food (bread, cheese, chocolate, sausages, mashed potatoes, etc.). During processing, attributes are imparted to the mix of molecules and assemblies until a product is created. A second connotation of the engineered structure is that one can determine and quantify its properties as if it were an engineering material. Due to the biological and non-equilibrium nature of foods, the structure of the product leaving the factory continues to change during storage, distribution, and preparation, until an ultimate structure is achieved just before eating. The sensorial evaluation of structure breakdown and physical attributes is perceived in the mouth as a complex process of flow, deformation, and fracture during mastication and swallowing, which constitutes the perceived structure.

2. Structure-Property Relationships in Foods

As is the case for any technological material, the microstructure of a food largely dictates its desirable properties (e.g., texture). Structure-property relationships describe the way in which physicochemical, functional, technological and even some nutritional properties of foods are related to their structure (see *Engineering Properties of Foods*, *Food Rheology*). It has been correctly pointed out that the first problem, from an engineering point of view, is to know whether one is dealing with the property of a material or that of a structure. Materials refer to pure substance and alloys (as may be the case in a few foods) that are homogeneous in composition (e.g., possibly a cracker). Structures, on the other hand, are composed of more than one material or phase. If these materials exhibit some regularity that is clearly discernible, it is said to have geometry or "architecture" (e.g., cells in an apple, fibers in meat). Thus, the microstructure of a food can only be understood when its architecture and elements are considered together. It is in the development of the structural (or physical) model of the food where microscopy becomes irreplaceable.

The complexity indigenous to foods lies in the intricacy of their molecular and supramolecular architecture constituting their structure. This complexity has been continually unraveled with increasingly powerful analytical techniques, such as microscopy, thermal and mechanical analysis and advanced spectroscopy, a direction in which food materials science is moving. Assuming the property and structure are clear, what kind of relationship does one want? Table 1 shows some examples of structure-property relationships imparted during processing and storage.

PROPERTY	EXAMPLE	MAIN STRUCTURAL ELEMENT
Texture	Hardening of stored legumes	Middle lamella between cells
Gelation	Thermoset protein gels	Protein strands in gel network
Diffusion of solutes	Salt impregnation of cheeses	Liquid-filled pores
Rheology	Emulsions	Droplets in suspension

Transport mechanism	Oil uptake during frying	Porosity of crust
Functionality	Water entrapment in low-fat spreads	Liquid crystalline lamellar phase
Heat resistance	Sporulation of bacteria	Ca^{++} accumulation in the core of spores
Emulsion stability	Stability of salad dressings	Macromolecules at interface of droplets
Flowability	Caking of food powders	Presence of amorphous state

Table 1. Some examples of structure-property relationships in foods.

In conclusion, most desirable properties of foods detected through the senses of vision, hearing, touch, and kinesthetics are a manifestation of their microstructure. Finding structure-property relationships in foods also has a futuristic dimension in which biotechnology and genetic engineering may contribute to tailor-make natural materials possessing improved characteristics.

3. Examining Food Microstructure

3.1. Light Microscopy

The compound microscope has been an important tool in the study of food materials. It has a resolution about 10^3 times smaller than the human eye and produces a magnified image of details unavailable to unaided vision. Here, resolution is the minimum linear distance between two points in the specimen for which they still appear as two points. Light microscopes (LM) now come in an almost infinite variety of configurations, but the essential sequence of components remains unchanged. Modern microscopes have built-in illumination, producing visible light that travels through a diaphragm and a condenser to focus and control the intensity of the light beam before it is transmitted through the specimen. A glass slide and cover slip bracket the specimen on an adjustable X/Y direction stage; light then enters the objective lens set in a revolving nosepiece and travels up the tube and through an eyepiece to form an inverted, enlarged virtual image, which is visualized by the eye of the operator; a real image may also be captured on photographic film or video. Focusing is achieved by adjusting the focal plane by varying the tube length.

The most common application of the LM is bright field illumination, in which light is transmitted from below through a relatively thin section or slice of material; the image is formed above the sample in a tube and viewed through the eyepiece magnified approximately 100 to 1000 times. Images can be photographed and measurements made on either an image or a micrograph. Specimens are examined at normal atmospheric pressure and therefore do not have to be dehydrated, but care must be taken to prevent wet mounts from desiccating during prolonged observation. Thus, sample preparation is relatively easy. Alternatively, mounts that are more permanent can be achieved using fixed, dehydrated, or embedded tissue.

Staining is a useful procedure because biological tissues are most often colorless and therefore lack contrast. Alternatively, contrast can be enhanced through phase contrast or differential interference contrast (Nomarski) optics, in which the phase of the light is altered and then recombined to yield improved differentiation. Although these two procedures lead to similar images, they employ different mechanisms to modify the light path. To convert a bright field microscope to a phase contrast, the condenser iris is exchanged for an annular diaphragm and a phase plate is mounted above the objective lens.

To convert a bright field microscope for interference microscopy, a polarizer and prism are added below the condenser and above the objective. Enhanced contrast and visibility of unstained tissues characterize the phase contrast image, while the interference contrast image has a distinct relief appearance and a shallow depth of field. Contrast between the two methods depends upon the degree of difference in the refractive index of an object transparent in bright field illumination from that of the surrounding medium. Thus, in some cases phase contrast gives the best image, while in others differential interference contrast is the superior technique. One method does not replace the other, but is complementary to it.

Polarizing microscopy, another contrast-inducing technique, has many applications in the study of food structure. In this form of light microscopy, plane-polarized light (light that vibrates in a single direction only) is allowed to impinge upon the specimen. If the material contains anisotropic or birefringent structures, i.e., those capable of rotating the light plane, the emerging light beam will be altered by twisting and partially extinguished. On the other hand, isotropic substances have only one refractive index and do not rotate plane-polarized light. A polarization microscope can be adapted from a bright field LM by inserting a polarizing prism or filter below the condenser (the polarizer) and one above the objective (the analyzer).

If both plates are arranged parallel to each other, plane-polarized light can be transmitted through to the eye. However, if their axes are perpendicular, no light will be transmitted and a dark field will result (so-called crossed Nicol prisms). When an anisotropic material is placed between crossed prisms, it will rotate some of the plane-polarized light and thus be visible. An isotropic sample will not disturb the extinction of the beam. Food starches have typical characteristics, sizes, and shapes that are observable using polarizing microscopy. Of particular importance in identifying the botanical origin of starch is the unique Maltese cross pattern produced by the crystalline nature of the starch granule.

-
-
-

Bibliography

Aguilera J.M and Stanley D.W. (1999). *Microstructural Principles of Food Processing and Engineering,* 2nd Edition. Maryland: Aspen Publishing Co. [This book deals with the structure of foods and its relation to physical, quality, and processing properties, and is fully illustrated with photomicrographs].

Aguilera J.M. and Lillford P. (1996). Microstructural and imaging analyses as related to food engineering. In *Food Engineering 2000,* (eds. P. Fito, E. Ortega and G. Barbosa-Cánovas), 23-38. London: Chapman & Hall. [This paper shows how microscopic information can be coupled with chemical analyses and image processing].

Heertje I. (1993). Structure and function of food products. *Food Structure* **12**, 343-364. [A nice presentation of food microstructure, written by an industrial scientist].

Kalab M., Allan-Wojtas P., and Shea-Miller S. (1995). Microscopy and other imaging techniques in food structure analysis. *Trends Food Sci. Technology* **6**, 177-186. [An illustrated review of microscopy techniques as applied to foods].

Lillford P. (1998). Food composites. Presented in the II Ibero American Congress on Food Engineering, April 1998, Bahía Blanca, Argentina. [A view of foods as composite materials and the relation to their microstructure].

Raeuber H.J. and H. Nikolaus. (1980). Structure of Foods. *Journal of Texture Studies* **11**, 187-198. [This paper attempts to classify foods according to their structure].

Vincent J. (1990). *Structural Biomaterials* (revised ed.). Princeton: Princeton University Press. [An introduction to the structure of biological materials and their relation to chemistry and engineering].

Biographical Sketch

José Miguel Aguilera is Professor of chemical and food engineering at Universidad Católica de Chile. His book, *Microstructural Principles of Food Processing and Engineering* (1999, Aspen Publishing Co.) was the first to introduce microstructure as a key variable in the study of foods. Professor Aguilera has lectured and performed research at several universities in North America and was the 1993 winner of the International Award of the Institute of Food Technologists (USA). Currently, he is Head of the Department of Chemical and Bioprocess Engineering and a consultant to several international organizations and food companies.