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Texturising by phase separation

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Abstract

The most common food processing operations, thermal and mechanical treatments, both affect phase state and texture of foods. The phase separation threshold for food biopolymer mixtures is usually below their concentrations characteristically found in food. Phase-separation underpins texturisation processes during food processing and digestion. The distribution of water between the phases, the adsorption of lipids between the phases, the deformation of dispersed particles in flowing water-in-water emulsions and the gelation of the phases result in the specific morphology and texture of food. A historical experience in texturisation includes the development of cooked food and texturized vegetable analogues of animal foods.

1. Introduction

Texture of a food means its quality as perceived by touch in the mouth and/or by the fingers. Food texture describes a set of structural and physical, including mechanical, surface properties and syneresis. Texturisation aims at creating a certain pleasing behaviour of food in the mouth. Food texturisation was historically used to improve and modify the texture of grains, vegetables, to produce analogues of meat, such as tofu, corry-tofu, aburage, etc (Lillford, 1986; Tolstoguzov, 1998, 2002). The understanding of texture origins is of importance to the understanding of food quality and digestion of food (Lillford, 1986; Tolstoguzov, 2002).

2. Incompatibility of food biopolymers

Thermodynamic incompatibility of macromolecules was discovered more than hundred years ago. Beijerinck (1896) described the immiscibility of aqueous solutions of gelatin and of an agar or starch. On mixing, the two solutions form water-in-water emulsions (W/W emulsions) in which, for instance, droplets of the gelatin solution are dispersed in the starch solution.

It should be stressed that unlike other macromolecular compounds, native globular proteins have an unusually high co-solubility and some of them are, probably, co-soluble in all proportions in spite of great differences in amino acid composition. This feature is obviously of key importance for the enzymatic function of proteins. However, denaturation of globular proteins results in the phase separation of their mixtures.

Thermal–mechanical treatments during processing govern, therefore, both phase state and texturising of conventional and formulated foods. Generally, a food contains a complex mixture of both native, denatured proteins and polysaccharides, which are thermodynamically incompatible. This means that food biopolymers have a low co-solubility. W/W emulsions are therefore the most representative structural component of both food and chyme. Phase behaviour and structure–property relationships of heterophase biopolymer

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mixtures have been systematically studied using model biopolymer mixtures and food systems such as thermoplastic extrudates, wheat flour dough, breads, ice cream mixes, low-fat spreads and some beverages (Tolstoguzov, 1993, 1997, 1998, 2002, 2003, Tolstoguzov et al., 1999).

3. Mechanisms of food texturisation

Texturising by phase separation usually includes several stages (or processes) differing in their mechanism and result. One or several of them determine the texture of a food depending on its composition and processing conditions. The first stage is a liquid–liquid phase separation that results in a W/W emulsion where the unlike biopolymers are concentrated in the different phases. The difference between the biopolymers in hydrophilicity and in molecular weight underlies their competition for water and the redistribution of water between the formed co-existing phases. This water redistribution phenomenon can also be used for concentrating polymer solutions and is called membraneless osmosis. The membraneless osmosis process, i.e. the diffusion of water through the interface between the two immiscible solutions of biopolymers, changes their rheology. One or both phases of the W/W emulsion can gel. The gelation occurs when the bulk concentration of a co-existing phase exceeds the critical concentrations of the biopolymers for gelation. The relationship between the co-solubility limits of the biopolymers and their critical concentrations for gelation determine the boundary conditions for the formation of mixed and filled gels. The phase separation usually occurs at a slightly higher range of concentrations than those of gelation. The critical concentration for gelation does not usually exceed 0.1–0.5% for anionic polysaccharides, while for proteins this value varies, e.g. from 1% for gelatin to 3–10% for most globular proteins. The phase separation threshold is about 2–4% for mixtures of gelatin with linear anionic polysaccharides and exceeds 12% for mixtures of globular proteins. This means that combinations of proteins and proteins with polysaccharides can lead to the formation of mixed gels that have two or more relatively independent three-dimensional networks.

The second stage of texturising is the deformation of liquid dispersed droplets in flowing food system that acquires an anisotropic structure. The latter can be fixed by gelation due to membraneless osmosis. Anisotropic fibrous, capillary and lamellar structures are typical of foods since during processing, food systems are always subjected to shear treatments, e.g. during mixing, stirring, shaking, pouring, homogenisation, centrifuging, pumping, heating, extruding and cutting. The stresses developed in a dispersion medium of a W/W emulsion subjected to shearing can deform and orient the liquid dispersed particles. This occurs if the viscosity of the dispersed particles is lower than that of the dispersion medium. Under such conditions, in flow, dispersed particles can take the shape of liquid fibrils. The competing process is drop coalescence, resulting either in larger spherical drops or in longer liquid filaments. The formation mechanism of fibres and lamellas has been called spinneretless spinning. This mechanism affects the quality of thermoplastic extrusion products, in particular. Anisotropic structures can be fixed by rapid solidification (gelation and/or vitrification). Mechanical properties of both isotropic and anisotropic biphasic gels are proportional to the volume fraction of the dispersed phase, i.e. they obey the additivity law (Tolstoguzov, 1993, 1998).

The third stage of texturising is an adsorption of lipids and/or other non-polar food components within the interfacial layer between the liquid aqueous phases of a W/W emulsion. The interfacial (or depletion) layer, with low-biopolymer concentration between co-existing aqueous phases, results from the mutual depletion of the macromolecules forming immiscible aqueous phases. Lipids added to a W/W emulsion may, therefore, be dispersed in one of the phases (usually in the protein-rich phase) and/or adsorbed at the interfacial layer. The lipid adsorption changes the deformability of the liquid dispersed particles in flow and greatly affects the formed texture. Lipids adsorbed within the interfacial layer could form thin layers between the immiscible aqueous phases. In sufficiently concentrated W/W emulsions, coalescence of these thin lipid layers can lead to honeycomb-like structures. Such honeycomb constructions made up of lipids and filled with aqueous phases are typical of many foods. A less than 30% lipid content can be sufficient for formation of the continuous lipid phase in low-fat spreads based on a biphasic aqueous system. Small gel granules with low adhesion to each other behave like microscopic ball bearings and give an impression of creaminess in salad dressings, dairy products and frozen desserts. Similar granular products based on starch granules have historically been used as cosmetic powders. Presumably, the same ball bearing effect of starch granules lowers the viscosity of wheat flour dough, one of the most concentrated food systems. Texturation technologies have been considered in several reviews (Lillford, 1986; Tolstoguzov, 1988, 1993, 1998, 2002).

4. Texturation by the change of state of water

Freezing is another method of texturation by phase separation. Freeze protein texturisation is one of the most ancient technique for soybean protein processing, e.g. corry-tofu manufacturing. It was also applied for producing textured soybean proteins used as meat extenders. A uniform fibrous protein structure is formed by freezing a protein suspension with concentration and gelation of protein phase between fibrous ice crystals. The freezing and separation of water in the form of ice can also be accompanied by liquid–liquid demixing of the protein phase. The fibrous structure can be fixed by microwave irradiation providing rapid heat deep inside the blocks of frozen protein suspension. Mechanical pressure can be applied to separate water from the porous fibrous protein gel (Tolstoguzov et al., 1999).

5. Conclusion

It should be stressed that thermodynamic incompatibility of macromolecules that differ chemically and structurally is typical of food systems. Food and chyme are therefore phase-separated systems. The interfacial (or depletion) layer with low-biopolymer concentration determines some features of W/W emulsions: (i) easy coalescence of dispersed particles (by depletion flocculation), (ii) their easy deformability in flow, and (iii) adsorption of lipid particles between the phases.

The texture of traditional and novel formulated foods, its formation, modification and/or preservation during processing (frying, cooking, freezing, etc) and storage is one of the key quality aspects of food. Food texture is therefore an important factor for the success of a food both in the market-place and as well as for consumption.

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