Food technology and nutrition: Challenges for colloid and interface science

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Abstract - Issues influencing food production and consumption are outlined. Some opportunities for using methods of colloid and surface science to study food emulsions and foams and their impact *in vivo* are discussed.

INTRODUCTION

Our food supply has come a long way since the era of the hunter-gatherer. This evolution has, in the more affluent societies, been fuelled by continually changing consumer attitudes, lifestyles and spending power. Large retailers and food processing groups are quick to use new technology to market products that meet consumer demand. In turn this raises consumer expectations leading to increased opportunities for research.

Life is full of dichotomies. In English some say "We live to eat"; others: "We eat to live". The first phrase encapsulates a wish for enjoyment, the second a desire to have good health. Health and enjoyment are the two forces in cultures everywhere that in varying degrees shape our diets.

In less affluent societies and certainly in early human diets, health was synonymous with survival. Such diets can be extremely varied with a wide range of plant foods. Interestingly animal foods were generally taken opportunistically (ref. 1).

In the late 1980's, food and health in the USA and the UK became associated almost entirely with food safety. Reported incidents of food poisoning increased markedly (ref. 2). This happened despite improvements in the handling of raw materials, in factory hygiene and significant advances in the understanding of the effects. New types of food and changing patterns of purchase and consumption imposed greater demands on those involved in food manufacture and distribution. From a food manufacturers viewpoint, the development of new products using for example milder processing or few additives and preservatives are likely to be increasingly restricted without adequate information as to the effect of physical and chemical constraints on their safety.

There is now emerging an increasing public consensus that diet plays a major part in the incidence of disorders such as cancer and cardiovascular disease especially in middle age and later life (ref. 3). The resulting advice emphasizes the importance of foods of plant origin and a wide range of nutrients including carbohydrates and dietary fibre as well as limited consumption of fats. The past few years have seen the development and aggressive marketing of low salt and low fat foods in both Europe and the USA. New ingredients such as low calorie sweeteners are in widespread use. The use of fat substitutes is just beginning. The demand for increased nutritional quality linked to convenience and enjoyment will impose further demands on research into the links between food microstructure and consumer properties including digestion and bioavailability.

Finally we note the increasing awareness and demand for so called functional foods in Japan - a huge market estimated presently to be in excess of £1 Billion. An increasingly aging population seeking the nirvana of health and longevity together with increased nutritional quality linked to convenience and enjoyment can only increase further demands on research.

Physical and biological science now offers new ways to approach in an integrated way the interplay between food and biological raw materials, their safe fabrication into quality products and the impact of these products on individual well being. In what follows I use examples from my own laboratory to highlight the role of Surface and Colloid Science.

EMULSIONS AND FOAMS

Many foods are emulsions of foams, during or after manufacture (ref. 4). In oil-in-water emulsions, the dispersed oil droplets generally possess lower density than the continuous aqueous phase. Unless the droplets are very small or very concentrated the density difference leads to the accumulation of droplets at the top of the container ("creaming") with consequent loss of perceived quality and increased potential for microbial spoilage. Most techniques to measure creaming (or sedimentation) are intrusive and applicable only to dilute systems. We have developed a technique based on monitoring the velocity of ultrasound through the dispersion. The technique is non destructive and non-intrusive.
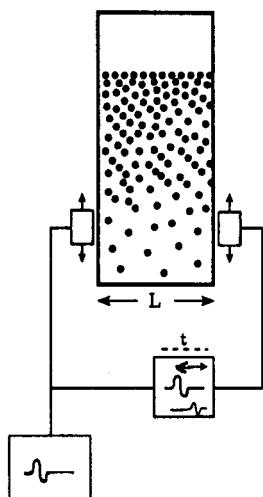

Fig. 1.
Schematic of apparatus used to monitor velocity of ultrasound in emulsions

In general the velocity v (= L/t) is a complex function of ultrasound, composition, particle size distribution and physical properties of the disperse and continuous phases. However, for sufficiently low frequencies a simple mixing equation describes the relationship between velocity v and particle volume fraction.

The terminal velocity v_s of a single spherical particle moving under gravity in a viscous liquid is given by Stokes' Law $v_s = \Delta\rho \, d^2 \, g \, / \, 18 \, \eta_o$ were $\Delta\rho$ is the density difference between continuous and disperse phases, d is droplet diameter, g acceleration due to gravity and η_o the viscosity of the continuous phase. Particles in a dispersion increase its viscosity and a simple treatment of this effect (ref. 5) yields $\eta(\emptyset) = \eta_o \, (1-\emptyset/\emptyset_m)^{-2.5\emptyset_m}$ where $\emptyset_m$ is the close packed volume fraction. For deformable liquid particles $\emptyset_m$ can obviously be greater than 0.64, the value associated with hard spheres. For emulsions that cream rapidly the approach yields satisfactory interpretation of the data. However when polysaccharides or similar polymers are added to the continuous phase, which is generally the case in food, η_o becomes large and the droplets rise relatively slowly. As a result, flocculation of droplets can occur and the creaming process is more complex. Using the ultrasonic method Robins (ref. 6) has studied a wide range of such complex creaming emulsions and clearly demonstrated how not only density profiles may be obtained as a function of time but also shown how drop size distribution may be obtained. Such distributions correlate well with light scattering. One can now be very confident that the ultrasound technique is of considerable value in emulsion studies. Approaches to modelling the process have also been made (ref. 7) and real time computer simulation may now be possible.

Building on this work, it is possible to investigate in detail compositional and structural changes occurring on micro-scales with a view to making important contributions to the understanding of factors that influence survival and growth of microorganisms in heterogeneous food stuffs.

A key factor conferring both ease of preparation and stability of both emulsions and foams is the nature and mobility of surfactant molecules at the two phase interface. A simple conductivity measurement is both sensitive and useful in qualitative studies. My colleague Dr Clark has reported such measurements. Fig. (2) shows data for foaming mixtures of β-lactoglobulin and Tween 20. At Tween to protein ratios less than 1:1 the foaming behaviour is unaffected. However higher levels of Tween destabilize the foam, shown by reduction in conductivity after 15 minutes. Minimum stability is observed at a ratio of 5:1. At greater ratios, foam stability rises. This behaviour is consistent with competitive displacement of protein by Tween.

The phenomenon can be further observed in a qualitative fashion via thin film draining experiments. Protein films drain slowly and uniformly; Tween films drain in a more rapid and chaotic fashion. One may deduce that unlike Tween molecules which are highly mobile at the interface, the protein molecules prefer to interact and form a thick layer. In order to measure directly the molecular diffusion, we have developed the so called FRAP method which reveals via fluorescence the molecular mobility at the interface (ref. 8). Fig. (3) correlates the change in protein diffusity as Tween is added with the corresponding change in foam stability. The Tween appears to reduce the ability of the protein to interact negating the viscoelastic mechanism. Size prevents the proteins diffusing rapidly and stabilizing the film via a Marangoni mechanism. Film instability results until the Tween concentration is high enough to dominate the surface dynamics.
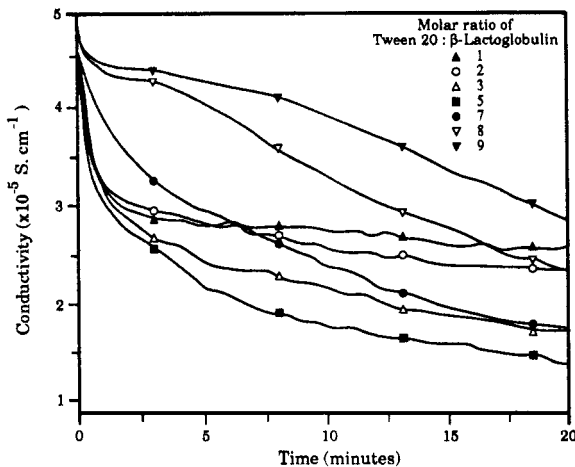

Fig. 2.   Foam stability curves for
          solutions of 0.2mg/ml
          β-lactoglobulin as a function
          of Tween 20 concentration.
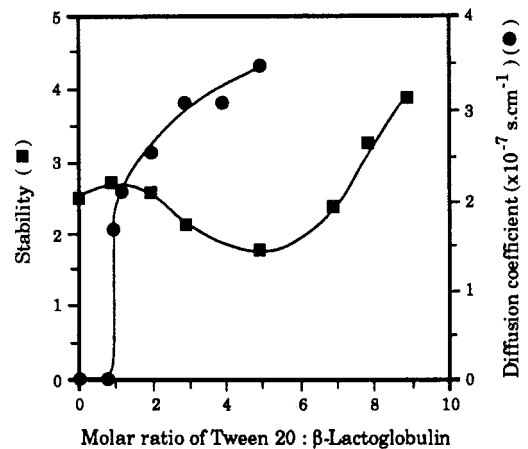
Fig. 3.   Foam stability and protein
          diffusion in films of lacto-
          globulin - Tween mixtures.

FRAP has been a recognised technique for 15 years but used mainly to look at membrane fluidity. We are now diversifying into this latter area to explore the activity of dietary components in biological membranes especially in the gut.

NUTRITION AND COLLOID SCIENCE

The processes that link food and health are complex and not well understood. Here I briefly illustrate how colloid science can aid our interpretation of a small part of this topic, i.e. digestion. The body absorbs food from an aqueous environment, the intestinal lumen. This is the layer adjacent to the brush-border membrane which forms the barrier between the external environment and our internal biological "machinery".

After eating, the state of food in our gut is not simple and the changes that take place as it moves through our intestines are only superficially characterized. Some insight into transport phenomena is possible by directly perfusing guar gum (ref. 9) a typical dietary fibre into the intestine of human volunteers using a multilumen tube. The solutions can be recovered by aspiration of fluid from a more distal site and absorption of water measured from the increased concentration of a non-absorbable solute (e.g. polyethylene glycol). Fluid absorption is reduced in the presence of guar.

The kinetics of nutrient uptake (e.g. galactose) by intestine can be studied more directly using isolated rings of small rat intestine *in vitro*. Absorption as a function of bulk concentration of the solute follows a pattern familiar to colloid scientists. Initially linear (Henry's Law), the absorption tends to saturate at higher solute concentrations. If a biopolymer such as guar is added to the solvent the relative absorption is reduced as one might expect Fig. (4)
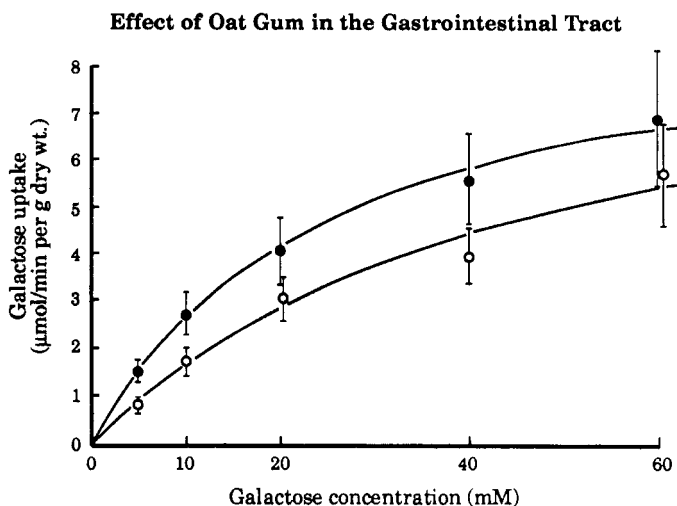
Effect of Oat Gum in the Gastrointestinal Tract

Fig. 4.   The sodium-dependent uptake of D-galactose by small intestinal rings in the presence (O) and absence (O) of oat gum (8.5 g/l), in Krebs-bicarbonate buffer, containing different concentrations of D-galactose. Values are means with their standard errors represented by vertical bars. Mean values were significantly different at 5, 10 and 40 mM ($P < 0.05$). Curves were derived from the Michaelis-Menten equation.

My colleague Dr Ian Johnson has made other investigations (ref.10) into the phenomenon and proposed the so called unstirred water layer concept. This asserts that the boundary layer adjacent to the brush-border membrane consists of viscous polysaccharides which control the rate at which nutrients are absorbed via diffusion. The physical mechanisms controlling this transport phenomenon are identical to the creaming processes discussed above. The insight we gain into such ways of controlling food absorption is relevant for both healthy people and others who may respond to dietary treatment (e.g. hypocholesterolaemic and diabetic patients).

The membrane of the gut is well known to be a rather complex affair. Equipped with specialized transport systems based on protein "carrier" molecules, many of which are linked to a source of metabolic energy, it can pump solutes "uphill" into the intestinal mucosal cell.

Saponins are widely distributed plant secondary metabolites. Most are highly surface active and many form complexes with sterols, including those associated with plasma membranes. This leads to membrane destabilization and cell lysis. Hemolytic saponins are highly toxic when given intravenously but less so when given orally. The nutritional significance stems from their hypocholesterolemic action. Recent work with alfalfa saponins suggests they may prove useful in control of cardiovascular disease. A variety of reasons have been suggested for this, one of which relates to the direct interaction of saponins with the membrane molecular structure (ref. 11). Our studies were made using the rat membrane.
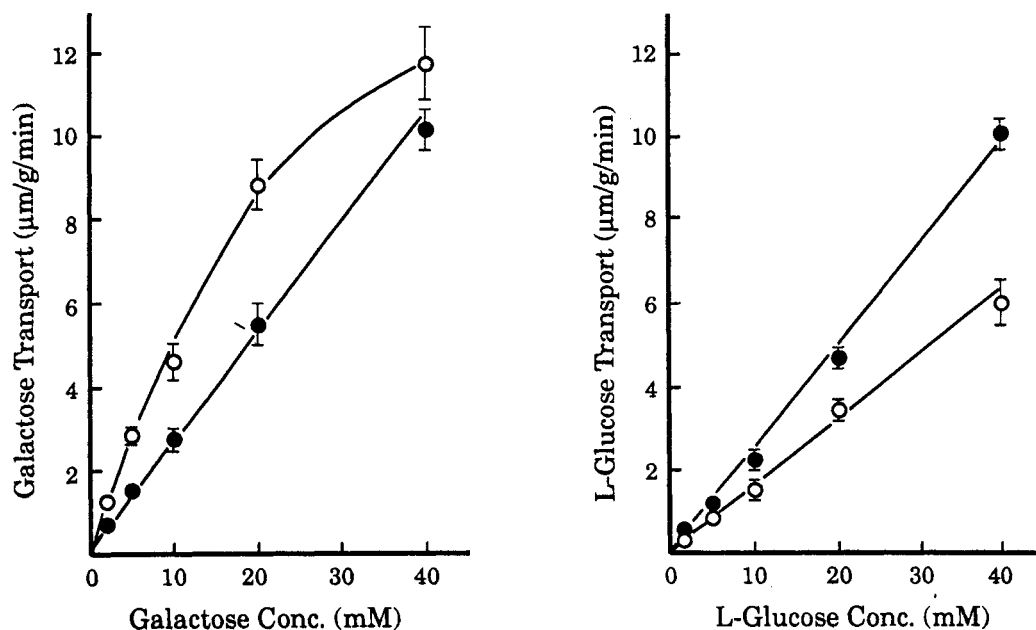
Fig. 5.   The effect of *Gypsophylla* saponin on the kinetics of galactose uptake and L-glucose uptake by everted rings of jejunum. In the presence of saponin (O), galactose transport was significantly lower than control values (O) at all concentrations below 40 mM (P < 0.01). L-Glucose transport was significantly increased by saponin at all concentrations (P < 0.05).

Fig. (5) shows uptake of L.Glucose by rat membranes as a function of bulk concentrations. In the presence of saponin, uptake was markedly increased. This may be directly linked to the ability of saponin to destabilize the membrane. However saponin reduces the transport of Galactose. This again may be related to the effect of saponin on the membrane. The activity of the protein carrier molecules which transport Galactose across the membrane has been diminished. Alternatively the same mechanism which increased L Glucose could also allow Galactose now to "leak" out via a backflux. Further studies of this are required.

CONCLUSIONS

I have given a brief outline of how some insights offered by colloid and interface science can be utilized not only to the benefit of the food industry in its constant quest for new products but also how parallel thinking can be used to study the impact of products in a diet. The outline is of necessity superficial in such a short review and much has been omitted. It is I believe an area that is ripe for innovation as interdisciplinary work becomes the norm. I sincerely hope this lecture will aid that process and we shall see as a result further development of the food supply in ways that continue to aid human society throughout the world.

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