Surprisingly, the hydrogen-bond-mediated attraction between catechol moieties can occur in an aqueous environment, where hydrogen bonds with water molecules may surround and passivate the catechols. Indeed, it looks as if exposed catechols are able to find each other, even when surrounded by water. Waite and collaborators discuss how the proposed bidentate hydrogen-bonding scheme between catechols is thermodynamically more favourable than the binding of the catechols to water.

The work of Waite and colleagues may also provide further insights into the nature of mussel-produced adhesive. For a strong glue to form, surface adhesion and cohesive bonding within a bulk material must be balanced. The emerging picture has been that the reduced (that is, not oxidized) catechol version of DOPA is responsible for surface adhesion[10]. DOPA oxidation to the quinone form generates cohesion via covalent coupling with nucleophilic functional groups, including amines[1]. Iron–DOPA bonds also contribute to cohesion, as well as to surface adhesion[6]. Waite and colleagues' work suggests that the reduced form of DOPA may also contribute to bulk cohesive interactions through hydrogen bonding, perhaps of the bidentate fashion. It may then turn out that mussel glue is also a self-healing hydrogel. ❐

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MATERIAL WITNESS

YOGHURT UNDER STRESS

PHILIP BALL

Anyone familiar with the usual response of small children to cooked courgette (zucchini) — "Urgh, slimy!" — will know that texture often trumps flavour when it comes to judging the palatability of food. Food scientists call this essentially rheological property 'mouth feel'. It is a critical aspect of the gustatory experience and commercial success of a dish or snack, but no one claims to have a good understanding of it. Rather like musical timbre, mouth feel is perceived as a single phenomenon but is the sum of many different properties, such as viscosity, hardness, elasticity, adhesiveness and so forth. Mouth feel integrates all the physical and chemical ways in which food interacts with the senses inside the mouth, and small changes in the formulation of a product, such as the amount of sugar or salt it contains, can make a big difference. Some efforts to profile mouth feel divide the sensory experience into dozens of characteristics such as chewiness, slipperiness and roughness, but it isn't clear exactly what primary 'dimensions' (if any) we instinctively use to classify it.

There is, however, some consensus that elasticity and fracture — how a food deforms inside the mouth, and how it breaks apart — are central to these judgements. All the same, the mechanisms of deformation and failure of gel-like media are imperfectly known. Foods such as jelly, tofu and hard cheeses behave as soft solids that fracture irreversibly when sufficiently stressed, in which regard they differ from other soft glassy materials such as emulsions and colloidal gels. This makes such protein-based gels more like brittle solids, although at face value that analogy sounds unlikely. Leocmach *et al.* now show that the comparison is well motivated, and that both soft and hard solids seem to show universal characteristics of brittle failure[1].

The researchers study gels of sodium caseinate, the salt of a key protein in dairy products — it is not too much to say that they are testing substances akin to yoghurt and cheese. They follow the time dependence of the strain at constant applied stress, and use ultrasonic imaging to map the strain field, visible thanks to microspheres added to the gel as acoustic tracers. In general, the strain develops slowly before finally accelerating towards failure at a well-defined time, τ_f, that is related to the stress via a power law.

Leocmach identify three creep regimes during this process. For times less than $0.1\tau_f$, the gel deforms viscoelastically, even though the deformation can be as large as 50 per cent. Then up to $0.9\tau_f$, regularly spaced cracks begin to appear. And from $0.9\tau_f$ until failure, the shear rate increases very rapidly and eventually diverges. Essentially the same three creep regimes are found in hard brittle solids, although the first of them generally involves plastic rather than elastic behaviour because of irreversible defect formation. These regimes are predicted by some fibre-bundle models developed originally to describe harder materials such as asphalt and fibrous composites[2,3].

Besides what this reveals about mouth feel — that such materials can retain a springiness for large deformations, say — the results might also cast light on the responses of living cells and tissues (they are also protein-based biogels) to stress, where the considerable elastic resilience to deformation might be a biologically useful property. ❐

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