Clever comestibles

Controlling the microscopic structure of foods could make diet products that taste as good as the real thing and help you feel fuller for longer. Emma Davies gets her teeth into some cutting-edge edible colloids

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You would surely have to try every trick in the book before attempting the celebrity no-food 'air' diet. But putting air into diet foods is a good way to help people to lose weight and it's one that scientists at Birmingham University, UK, are busy working on. They are one of many teams of colloid scientists using physical chemistry to create 'designer' food systems to help fight the global obesity crisis.

It's all about creating diet or nutrient-packed foods that make us feel satisfied – as far removed from the air diet as possible. For example, gel-coated air bubbles feel just like fat droplets in the mouth. Emulsions that are cleverly designed to stay intact until they reach the small intestine can make you feel fuller for longer. Meanwhile, hiding water inside oil droplets could allow food producers to cut fat and salt content without changing the appeal of a food.

There is an urgent need to cut down on dietary fat to deal with obesity and its associated chronic diseases, says Ian Norton, a microstructural engineer at Birmingham University's chemical engineering department and former chief scientist at Unilever. Many people are reluctant to change their eating habits and avoid 'light' versions of foods, thinking that they will not taste as nice as the fat-filled alternative. The thinking among many food colloid scientists is that the best way to help people to reduce fat consumption is to engineer low-fat food products that really are as good as the real thing. You can't cut all the fat in a food without destroying its quality, but you can blend in colloidal systems that are designed to be undetectable in the mouth.

Food colloids can be highly complex systems, but in general one substance – usually oil or water – is microscopically dispersed in another. Emulsions are perhaps the most widely used food colloids; salad dressing is a simple oil-in-water emulsion, while margarines are made from droplets of water dispersed in a fat phase, or water-in-oil emulsions.

In the air

It is easy enough to whip air into a liquid, but very hard to keep the bubbles stable so that the product can be stored for long periods. Norton's Birmingham team has found a way to make tiny air bubbles that are stable in liquids for months in what they call 'air-in-water' emulsions. The researchers coat the air bubbles in highly surface-active proteins called hydrophobins, which are extracted from fungi. The proteins assemble at the surface of the bubbles and aggregate to form gel-like structures.

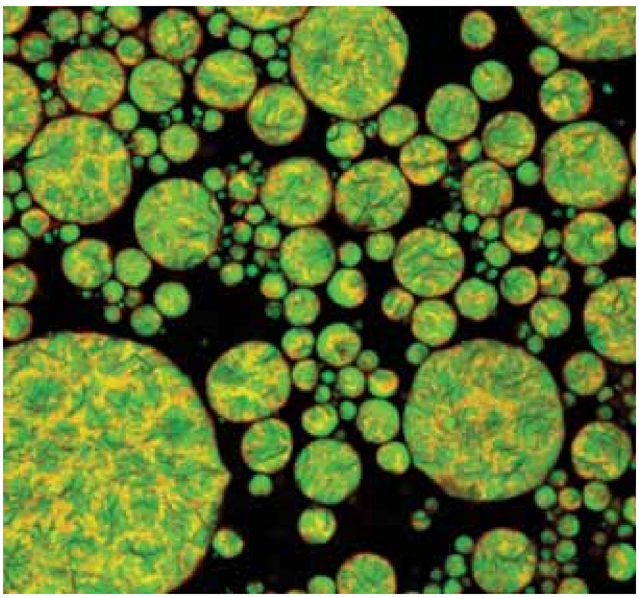
The bubbles are under 100μm in diameter – the same size as emulsion oil droplets – and the theory is that air-filled emulsions could be mixed with standard food emulsions such as salad dressing or sauces to cut fat levels without affecting product quality. But the hydrophobins can only be extracted in small amounts from cell cultures, making them prohibitively expensive, says Norton. He believes that 'biotechnology might fix this in the future'. In the meantime his group is working on lower cost protein alternatives.

Another potential way to cut fat content is to hide even smaller sub-micrometre drops of water within the oil droplets of an emulsion, in what is known as a multiple or duplex emulsion. The emulsions can be mixed invisibly into sauces and dips to cut fat content. The hidden inner water droplets are undetectable in the mouth and the body is fooled into thinking it is consuming a luxurious high-fat product.

The beauty of the duplex systems is that water-soluble nutrients such as vitamins and minerals can be hidden in the inner water phase, away from the oil phase and protected from other water-soluble compounds that they would normally react with in the food. The contents of the inner droplets will not be tasted and can in theory be released at a controlled rate in response to stimuli in the body such as change in pH or temperature.

In short

- **Colloids like emulsions and suspensions are a normal part of many foods' structures**
- **Engineering new types of food colloids can help reduce fat or salt content or deliver vital nutrients**
- **Slowing digestion by modifying fat emulsions can suppress appetite and make you feel full**
- **The choice of surfactants for stabilising food colloids is highly regulated, but certain proteins and bile acids could offer new options**



IAN NORTON

Engineering the size and surface structure of emulsion droplets can change their taste and how they are digested

Duplex emulsions (water-in-oil-in-water) could also be used to cut salt levels if salt is restricted to the outer water layer and the inner droplets are kept salt-free, says Norton. The idea is that consumers will perceive the product to have a higher salt content than it actually does.

Yet, restrictions on the emulsifiers that can be used in food systems hamper their emergence on the market. Duplex emulsions are quite unstable and likely to break down as the water moves from the inner droplet to join the bulk. The most commonly used research emulsifier to stabilise the inner water droplets is a bulky molecule from castor beans called polyglycerol polyricinoleate (PGPR), which is prohibited in most food systems. Norton is working on the problem and he and his team have found a way to encase the inner water droplets in shells of tiny fat crystals, in what is known as Pickering stabilisation.

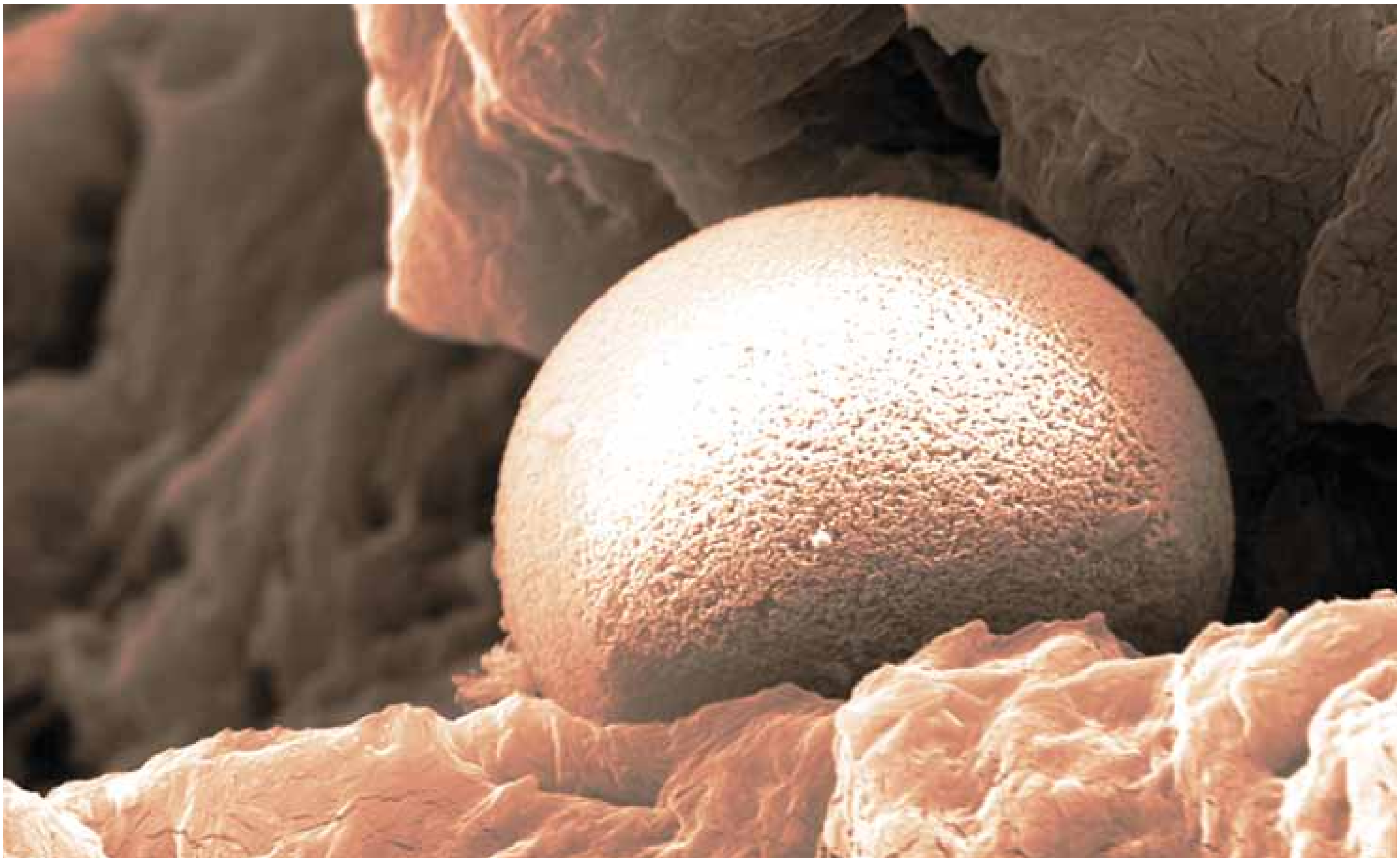
Full on fat

Colloid scientists are not only turning their attention to cutting fat levels, they are also creating food systems that are digested more slowly, making you feel fuller. 'Convenience foods are too easily digested,' says Norton. Nutrients are taken into the body too quickly and tend to be stored instead of being used. No sooner have you finished your meal than you are thinking of the next one.

Dutch company DSM already sells an oil-in-water emulsion called Fabuless, which can be incorporated into food products. Surface-active galactolipids from oats coat and protect the oil droplets as they pass through the stomach and most of the small intestine. DSM claims that the droplets are not fully digested until they reach the section at the end of the small intestine called the ileum. There, the fat triggers the body's 'ileal brake', sending a hormone signal to the brain telling you that you have had enough to eat.

Researchers at the Institute of Food Research (IFR) in Norwich, UK, have long focused on this ileal brake, carefully designing colloidal systems that don't break down until they hit the ileum. Slowing digestion not only makes you feel fuller, it can also keep encapsulated oil-soluble nutrients such as vitamin A in the body for longer.

Surfactant bile salts produced in the liver are key to fat digestion. 'Bile salts are unique in terms of


IAN NORTON

their molecular structure – they are not like conventional surfactants,' says Peter Wilde, who works on the IFR's food structure and health programme. The bile salts are flat, with two faces: one hydrophobic and the other hydrophilic. They adsorb to the surface of fat droplets and play a crucial role in knocking off proteins, allowing lipase enzymes access to set about the fat digestion process called lipolysis.This breaks down triglycerides into fatty acids and monoglycerides or glycerol.

By building stronger protein networks the IFR researchers have been able to limit bile salt adsorption at the surface of fat droplets and therefore slow the rate of lipolysis.

Wilde is now doing a 'more comprehensive analysis' of lipids released during digestion. 'Until now we have just looked at the interfacial composition and how that affects the rate of lipid digestion. Now we want to look at what is going on beyond the interface,' he says.

Wilde is also working on an oleic acid project to try to develop new systems that make you feel full. 'We know that unsaturated fatty acids such as oleic acid and linoleic acid give a decent satiety response compared with other fatty acids and we know that there is a receptor in cells for an oleic acid derivative,' he says. Wilde is working with a team led by Gary Frost, chair in nutrition and dietetics at Imperial College London, UK, to design systems that will stimulate these receptors and set off fullness signals. There are two possible ways to do this, says Wilde. One is to design an emulsion to delay digestion so that the key fatty acids are delivered further down the gastrointestinal (GI) tract. The other is to encapsulate fatty acids such as oleic acid in a medium that is resistant to digestion.

Cogitate and digest

Julian McClements, a food scientist at the University of Massachusetts, US, has also worked on delayed digestion systems. 'We recently encapsulated emulsion droplets in alginate, a dietary fibre that doesn't get digested until the small intestine,' he says. Desired nutrients, especially those that are highly water-insoluble and difficult to get into the diet, could be transported inside the emulsion droplets.

In a separate project, McClements is testing emulsions containing various compounds with possible anticancer properties such as circumin, found in turmeric, and polymethoxylated flavones (PMFs) from orange skins. 'If you encapsulate them in an emulsion system, can you increase the amount that gets into the blood and increase their efficacy?' he asks. The project is at an early stage, but McClements is confident of making significant progress in the next three years.

He uses in vitro digestion models to estimate how much of an encapsulated compound would be released on digestion. Emulsions pass through various treatment systems, including an acid environment with a pepsin enzyme and other levels with various other enzymes and bile salts. He then works with Hang Xiao, an anticancer specialist at Massachusetts who does cell culture tests and uses animal models to test the emulsion systems.

'We are also trying to increase bioaccessibility by changing the oil type or particle size of emulsions,' says McClements. This is where nanoemulsions come in. The theory is that by making the droplets smaller than 100nm in diameter, you can increase the body's uptake of encapsulated nutrients, largely because of the increased surface area. But it is not always that simple, as McClements's recent work on nanoemulsions stabilised with whey protein isolate has shown. The

Emulsions can be used to reduce levels of fat and salt in food, or package up desirable nutrients

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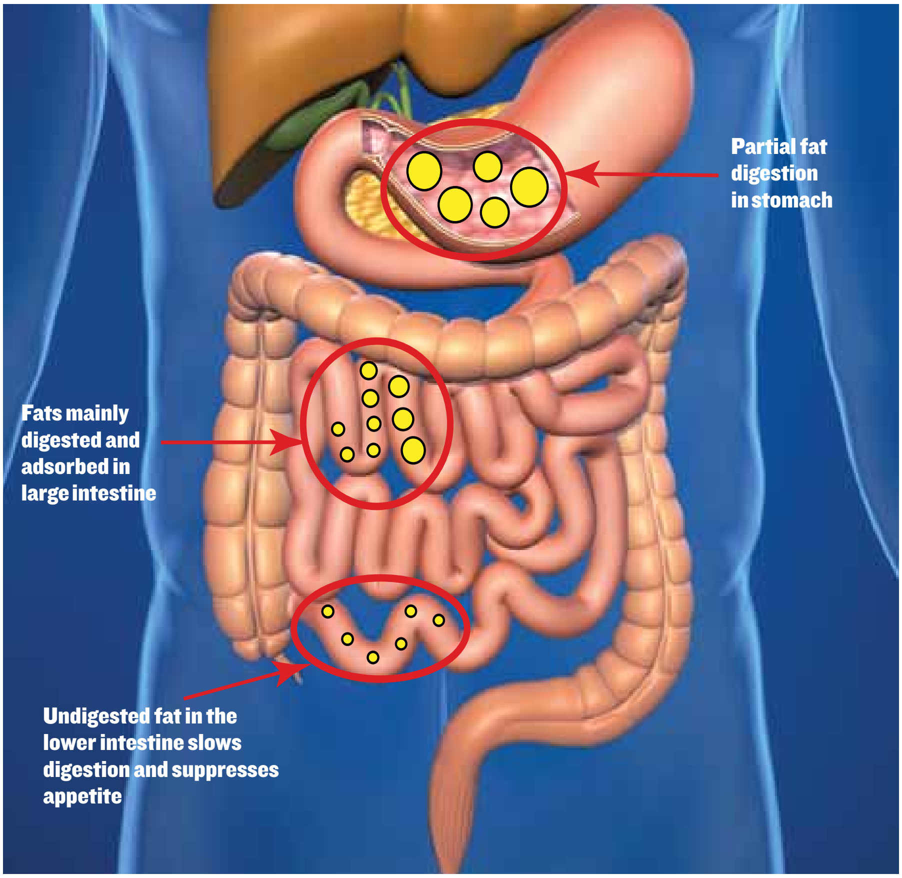

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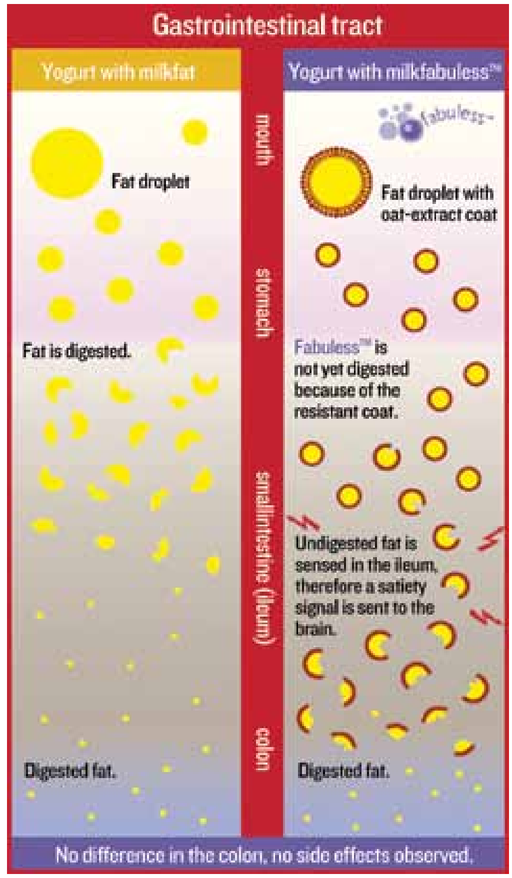

DSM

nanoemulsions appeared to have better stability to pH changes, salt addition, thermal processing and freezing–thawing than conventional emulsions. But, crucially, the conventional emulsions were digested more readily and had better oxidative stability. 'When you go really small, you change the interfacial characteristics as well,' says McClements. 'Everyone claims that smaller particles increase bioavailability, but I don't think that the empirical evidence is there a lot of the time.'

As with all things nano there are also concerns over potential health risks. For example, could the nanodroplets change the biological fate of bioactive components within the gastrointestinal tract? Also, making nanoemulsions requires different surface-active compounds, which may not be as body-friendly as the standard milk proteins.

A drop in the ocean

Harjinder Singh, co-director of the Riddet Institute at Massey University, New Zealand, leads a team with a 'very strong focus on how materials behave in the GI tract'. The team tests how factors such as droplet size affect digestion using a possum stomach, which can be kept alive in a chamber for a few hours. 'We plan to look at the detailed interactions of droplets with mucosa in the small intestine,' he says.

Singh has achieved commercial success by encapsulating omega-3 fish oils in oil droplets stabilised using a milk protein mix. By hiding the fish oils inside 200–300nm oil droplets they can be added to foods at high concentrations without giving any unpleasant fishy odours or taste. The droplets also protect the oils against oxidation. In 2006, Riddet became part of a joint venture with a New Zealand company called Speirs Group, set up to commercialise the emulsion systems. In 2007, Speirs Nutritionals opened manufacturing facilities and the company now has an exclusive agreement with UK speciality chemicals company Croda, which is putting its omega-3 fish oil concentrates into the Speirs emulsions to create a product called Ωmelife.

This can be added to a range of drinks and food products, including breads and pizza bases. The emulsion droplets are stabilised using a mixture of whey proteins and caseins from milk, which are heat treated before the emulsion is made to create strong stabilising networks, explains Singh.

Encapsulating fats to slow their digestion can exploit the 'ileal brake' to help people feel fuller

'Nutrients, especially those that are difficult to get into the diet, could be transported inside emulsion droplets'

Industry appeal

There is a great deal of industry interest in new colloid systems especially when it comes to encapsulating nutrients. 'As the technology develops there are some more cost-effective solutions to encapsulating materials in an intelligent way,' says Wilde. But developing encapsulation systems is not as straightforward as for pharmaceutical products. Encapsulated food systems may need to survive heat treatment, storage and cooking. 'We will need a lot more research to develop systems that survive those processes,' says Wilde.

'It's an exciting area,' says McClements. 'Exciting and challenging,' says Norton.

Emma Davies is a science writer based in Bishop's Stortford, UK

Further reading

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