Rheological control and understanding necessary to formulate healthy everyday foods

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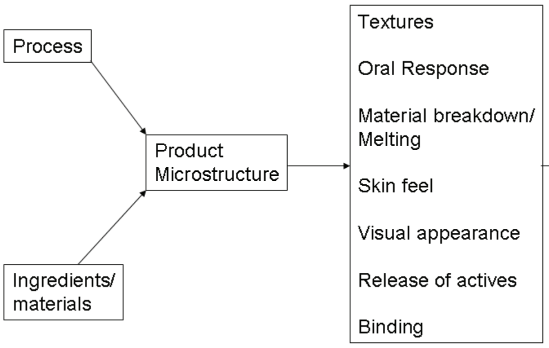
INTRODUCTION

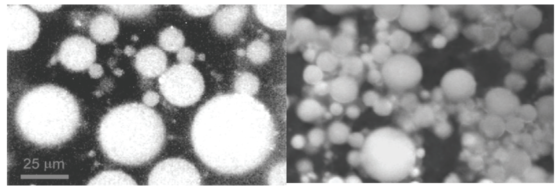
There are a number of issues with people's diets; these include the presence of high levels of fat, carbohydrates and salt. There is clear evidence that the consumption of high calorific and or salty diets leads to chronic diseases such as obesity, type II diabetes and hypertension[1]. However, most people are reluctant to change their traditional or even "inherited" dietary habits. This gives the formulation scientist (microstructural engineer) an opportunity to develop the science and understanding necessary to produce high quality everyday foods with lower calories and salt, but which have all the qualities and consumer perception of the unhealthy food.

In order to do this we need to control the rheological properties as well as control the overall taste and mouth feel of the product. A good example to illustrate this is mayonnaise; many low fat formulations suffer in the market place because their textures are significantly different to the full fat original. The reason is that often the approach is to replace some of the fat with swollen starch granules or with hydrolysed starch. Unfortunately, starch does not sufficiently resemble fat to fool the mouth, and so the products are generally described as having a "pasty" feel. It seems the reason for this is that the fat in mayonnaise exists in soft spherical droplets with an average size of about 5 µm. The starches used by the manufactures are gelatinised to various states but is always in the 10's to 100's of µm and diffuse. The resulting rheological changes are easily identified by the consumer.

We are developing several routes to reduce the amount of fat in emulsion based water continuous products without changing the sensory properties. What we and others have shown is that it is impossible to remove all of the fat as this is detrimental to the flavour release[2]. What is possible is to removed a significant proportion of the fat and, if done using a microstructural approach (Fig. 1) we can maintain the physical attributes associated with the full fat version.



(a)



(b)

Figure 1 (a). Schematic representation of the microstructure approach, showing typical material properties and consumer aspects that are impacted by product microstructure along with which parameters can be used (i.e. process and starting materials/ ingredients) to design the product microstructure.

Figure 1 (b). Micrographs of a water in water emulsion (left picture) in which the microstructure has been designed to match the oil in water emulsion found in mayonnaise (right picture) in which the oil droplets are the light grey spherical particles. The magnification is the same for both pictures, the scale bar is 25µm.

SHEARED GELS (FLUID GELS)

An example of how fat replacement using a microstructural approach can be developed is the use of sheared gels, e.g. agar, carrageenan, alginate[3-6]. These gel particles are produced by cyclising the network while they are being formed thus producing spherical particles of gel with each particle having the same rheology as the bulk gel. If the majority of the oil droplets in a mayonnaise are replaced by soft elastic spherical gel particles then the overall bulk rheology of the mayonnaise can be matched (Fig. 2). In this figure we have shown a flow curve for a full fat mayonnaise and compared it with a reduced fat (3% compared to 80% in the full fat version) emulsion in which the oil droplets have been replaced by sheared agar gel (5%), assembled as a particulate gel. This combination of oil droplets and gel droplets has provided a yield stress and a flow behaviour which are similar (although still not an exact rheological match) to the full fat emulsion and with a close match in sensory properties when tested by a consumer panel.

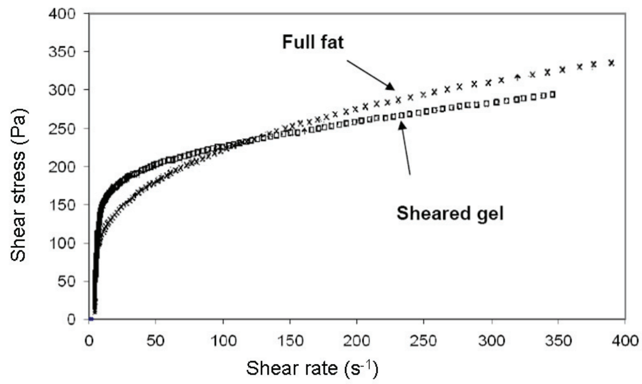


Figure 2. Stress strain curve for a 5% sheared agar with 3% phase volume of oil droplets (droplet size ~ 1 µm) compared to a full fat mayonnaise (Hellman's) using a roughened cone and plate geometry on a rheometrics instrument.

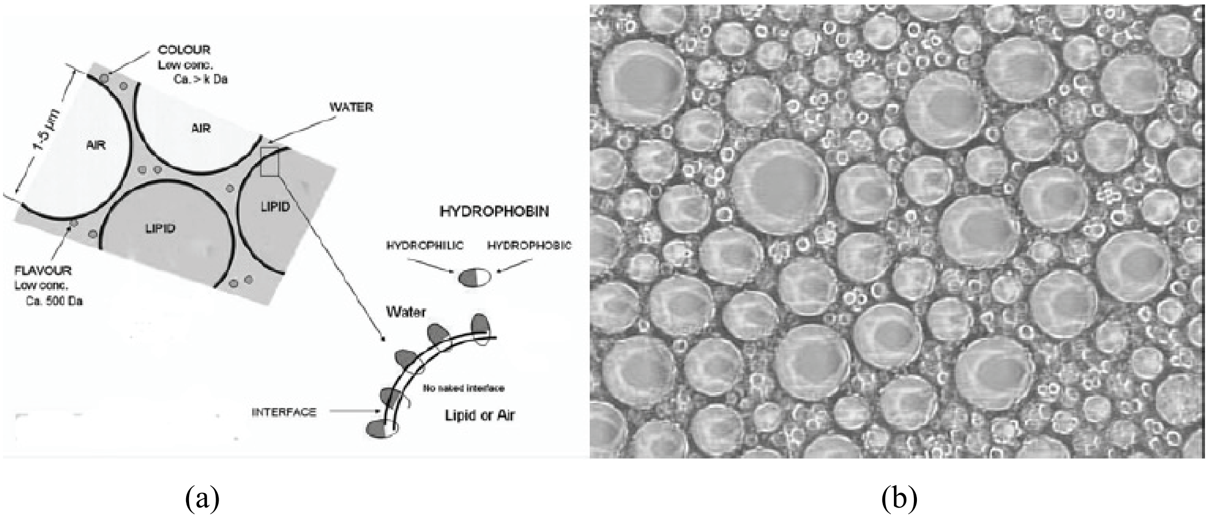


Figure 3. A schematic representation of the hydrophobin stabilised mayonnaise (a) and photomicrograph (b) picture width 100µm, of an air and oil filled emulsion after 4 days storage. Oil droplets have a mean diameter of ~8µm and the air filled droplets have a mean diameter of ~2µm.

AIR FILLED EMULSION

Sheared gels are not the only route that might be used to replace the fat in mayonnaise or sauces. Another stratagem is to replace a significant proportion of the fat with stabilised air cells which physically (size and shape) and rheologically resemble fat droplets. The construction of air filled emulsions has recently started at Birmingham using a novel group of proteins (hydrophobins). These proteins assemble at and subsequently stabilise air/water or oil/water interfaces via a gel like network which gives elasticity to the interface[7] and an elastic restoring force as the air droplets try to ripen on storage. By designing the interface to give the air droplet a rheology which matches the oil droplets and stops ripening for the months necessary for product stability, an air filled emulsion can be used to construct products. (The structures are shown schematically in Fig. 3). In order to give both a rheological match while maintaining the flavour of the product we are using a combination of air and oil filled emulsions within a single product structure (a triphasic emulsion).

WATER IN WATER EMULSIONS

An alternative approach is to use water in water emulsions. These may be regarded as composites where one of the components forms a continuous network across the entire system and the other serves as a gel filler[8] i.e. resembling an oil/water or water/oil system. Water in water emulsions constructed in the right way, have been shown to have all the rheological properties of spreads and margarines. This means that they can be used to produce products which are not just low in fat but are zero fat[2,5]. Again the design strategy is to create a microstructure that mimics that of the high fat product and thus gives material properties, mouth-feel and sensory properties of a full fat product[9]. An ingredient which has been used very successfully is low dextrose equivalent maltodextrin gels[10] which when used in mixed biopolymer systems can mimetic the organoleptic properties (failure, melting etc) and material properties (e.g. spreading, scooping etc) of the high fat products. Fig. 4 shows some of the data we obtained for a gelatin/maltodextrin water in water emulsion in which we have added liquid oil to produce a low or very low fat spread with virtually no saturated fatty acids (safa). In the figure we compare data obtained for fat continuous low fat spread (Flora light) containing ~35% fat in which the material properties (spreading, plasticity etc) depend upon crystallization of the saturated fats to form a fat crystal network.

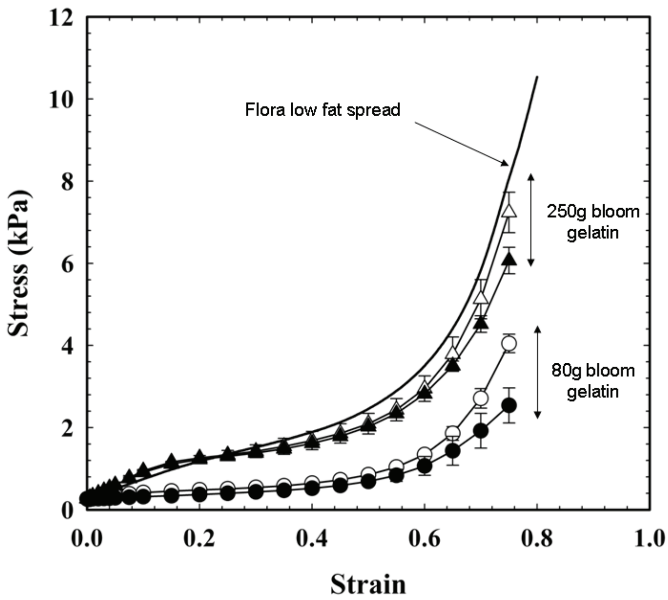


Figure 4. Compression stress/strain curves obtained for a low fat spread (flora) and water in water emulsions (20% maltodextrin / 4% gelatin./ 0.1m NaCl) using an Instron material tester. The oil phase was sunflower oil either; 20% open symbols or 40% filled symbols, emulsified with 0.5% (w/w) Tween 80, droplet size~ 5μm.

Fig. 4 demonstrates that by producing a water in water emulsion with similar material properties to the Flora and then by adding either 20 or 40% liquid vegetable oil as a fine emulsion the flow and fracture properties can be matched. As would be expected the material properties of the water in water emulsion depend upon the continuous phase and as such depend on the bloom strength of the gelatin. As the oil is emulsified into the water in water emulsion as fine droplets the properties have only a weak dependence on the oil content, which appears to be behaving as a soft filler.

ORAL PERCEPTION OF FAT

In order to develop foods that have the perception of fat when little or none is present, we need to understand how the fat behaves within the human gastro intestinal tract i.e. the mouth, the stomach and the intestine.

In terms of rheological response, the mouth is the most interesting[11]. Here the physical sensation of fat tends to be one of a mixture of tribology and rheological response, not as often reported simply dependent on the viscosity at $100s^{-1}$. Fig. 5 shows how the frictional coefficient changes for a range of samples (emulsions with oil levels 1% to 55%, pure water and pure vegetable oil) as a function of the rotational speed of the plate in a tribometer. As can be seen at low rotational speeds (the tribological region - were the gap between the ball and plate is the smallest) the pure water and 1% fat emulsion have a much higher frictional coefficient than emulsions with 20% oil or more, or the pure sunflower oil. The emulsions containing 20% or more oil have Stibeck curves at low rotational speeds that are very similar to the pure vegetable oil. The emulsions with 15% oil falls between these two sets of curves. As the rotational speed of the disc increases the gap between the ball and plate increases and the flow becomes what is know as a mixed regime (hydrodynamic and tribological). In these conditions emulsions with greater than 20% oil match the pure oil. Finally at very high speeds where the gap is greatest (the hydrodynamic regime) then it appears as if emulsions with greater than 55% oil are required to match the liquid oil.

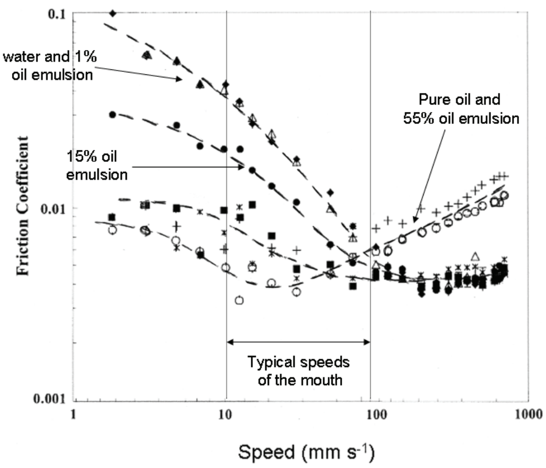


Figure 5. Stibeck curves for o/w emulsions containing different levels of fat10 (pure oil ○, 1% oil Δ, 15% oil ●, 20% oil ■, 30% oil x, 55% oil +, and pure water ♦) at 35°C.

By comparing this type of data[11] with sensory perception data (of a trained panel) it has been shown that the best correlation between the rheological measurement and the human sensation occurs with speeds between 10 and 100 mms^{-1} (the mixed regime). This data suggests that, a lower limit of fat content in emulsion based products to give acceptable performance on consumption is between 15 and 20%. However, in the future it might be shown that particles of gel or air filled emulsion droplets can be made to give the same thin film behaviour as the pure oil or high fat emulsions. Clearly more work is required.

CONCLUSIONS

In this paper we have discussed the use of microstructural engineering to control and manipulate rheological properties of low fat foods which are required to address a number of pressing concerns for the modern food industry and the population in general. We are using this approach to construct materials to reduce the calorific content, deliver flavour, reducing the salt content of processed foods while maintaining consumer acceptance and satisfaction. The next period of development for the food industry looks to be very exciting as will be the challenges faced by the microstructural engineer and rheologist.

REFERENCES

1. I. T. Norton, P.J. Fryer and S. Moore (2006) Product/process integration in food manufacture: Engineering sustained health. Aiche Journal, 52, 1632-1640.

2. M.D. Meiners, T.V. Merolla, M.S. Smagula, D.L. Bernardini and E.M. Harkabus, EP 0 477 827 A2, 1992.

3. F.W. Cain, A.H. Clark, P.J. Dunphy, M.G. Jones, I.T. Norton and S.B. Ross-Murphy, EP 0 298 561 A2, 1989.

4. N.D. Hedges and I.T. Norton, EP 0 432 835 A1, 1991.

5. I.T. Norton and J. Underdown, WO 95/35036, 1995.

6. B.B. Gupta, S. Kasapis, and S. Alevisopoulos, GB 2323092 A, 1998.

7. M. De Vocht, PhD Thesis, University of Groningen, 2001.

8. V.B. Tolstoguzov, in: Functional Properties of Food Macromolecules, eds. J.R. Mitchell and D.A. Ledward, Elsevier, London, 1986, 385.

9. I.T. Norton, P.W. Cox and F. Spyropoulos, Gums and Stabilisers for the Food Industry 14 (2008), RSC press, eds G. Philips and P. Williams, 293.

10. S. Kasapis, E.R. Morris, I.T. Norton and A.H. Clark, Carbohydr. Polym., 1993, 21, 243.

11. M.E. Malone, I.A.M. Appelqvist and I.T. Norton, Food Hydrocolloid, 2003, 17, 763.