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COMBINED INSTRUMENTAL AND SENSORY MEASUREMENT OF THE ROLE OF FAT IN FOOD TEXTURE

R. J. Marshall

AFRC Institute of Food Research, Reading Laboratory, Shinfield, Reading RG2 9AT, UK

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ABSTRACT

Fat is an important component of many foods, and changes in the fat type and level may result in unacceptable textures. Using processed cheese analogues containing four fats of different hardnesses and a combination of structural, rheological and sensory analysis it was demonstrated that the role of fat depends on its physico-chemical properties. These analyses separated cheeses into two groups according to the hardness of the fat. Modification of the properties of the fat may allow control of the fracture properties of solid foods and hence texture.

Keywords: *Fat*; *composite food*; *rheology*; *fracture*; *structure*; *sensory*; *psychorheology*.

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INTRODUCTION

Fat plays a crucial role in determining the texture of many foods. It imparts essential mouthfeel characteristics (Drewnowski, 1987) and, in solid composite foods, determines fracture properties (Marshall, 1990). In liquid foods fat may affect viscosity, and this can be related directly to sensory characteristics via simple models (Sherman, 1977; Kokini, 1987). In semi-solid and solid foods, fat has a more complex role in which the mechanism of fracture is affected (Marshall, 1990). This effect depends on the physico-chemical properties of the fat and the degree of interaction with the surrounding matrix (Marshall, 1990).

The influence of fat on fracture properties means that any change in fat will affect the integrity of the food. Yet there is considerable medical and social pressure to reduce the dietary intake of all fats (DHSS, 1984). Simply reducing the amount of fat in a given food results in abnormal and unacceptable textures. For example, reduced-fat Cheddar cheese is firmer and more elastic than normal (Emmons *et al.*, 1980). This defect may be partly overcome by increasing the moisture content of the cheese during manufacture, but the texture is still noticeably abnormal. Reducing the fat content of confectionery, cakes and pastries also causes textural problems. Only in some semi-solid foods, such as ice-creams or low fat spreads, can fat levels be significantly decreased and acceptable textures maintained. Even then, these products have to be reformulated and stabilisers added (Haumann, 1986).

COMPARISON BETWEEN MASTICATION AND RHEOLOGICAL MEASUREMENTS

During eating, the changing textural properties are perceived by the consumer in a very complex series of events (Bourne, 1982). A piece of the food may be first bitten off from a larger piece using the incisors. Gradually moving the food backwards in the mouth, it is torn apart with the cuspids and bicuspids and ground into smaller fragments by the molars. Saliva is added during these events to lubricate the process, extract flavours and initiate some digestion of carbohydrates. Eventually the food is ready for swallowing. The particle size on swallowing may depend on the type of food but also on the state of dentition. Those with poor masticatory function, dentition or false teeth tend to swallow larger particles than those without such impediments (Yurkstas, 1965). Possibly one of the most significant events that occur during chewing, that relates to texture perception, is the initial and continued fracture of the food.

The consumer perceives the texture of the food throughout mastication. He may perceive the amount of work needed for chewing, the particle sizes, the amount of moisture or the coating of the inside of the mouth, for example. At the Institute of Food Research, we are presently engaged in research which relates instrumental measurements of texture to these complex events. It is hardly surprising that many such attempts have met with varying degrees of success (Green *et al.*, 1985). Shama and Sherman (1973) suggested that more meaningful relationships could be obtained if the deformation rates during instrumental testing were of the same order as those during mastication and the tests deformed the food sample beyond its point of failure. The geometry of the test system may also influence the relationships (Green *et al.*, 1985).

The rheological parameters measured by these various tests may not relate directly to the sensory results. As described earlier, the sensory textural properties of a solid food are a result of a complex mixture of physical phenomena that occur during eating (Drake, 1987). It is therefore unreasonable to expect them to relate directly to relatively simple rheological parameters. Thus, one can propose that a sensory textural attribute such as that known as 'chewiness' (whatever that may be) may perhaps be described rheologically as some combination of work, elasticity, time, etc.; similarly, 'moistness' as a combination of moisture content, fat content and fat solid/liquid ratio (Sherman, 1977; Drake, 1987; Kokini, 1987; Booth, D. pers. comm. 1989). However, in order to develop this further we need to know far more about the process of the perception of the texture of solid foods and about the material properties of these foods both before chewing and after fracture.

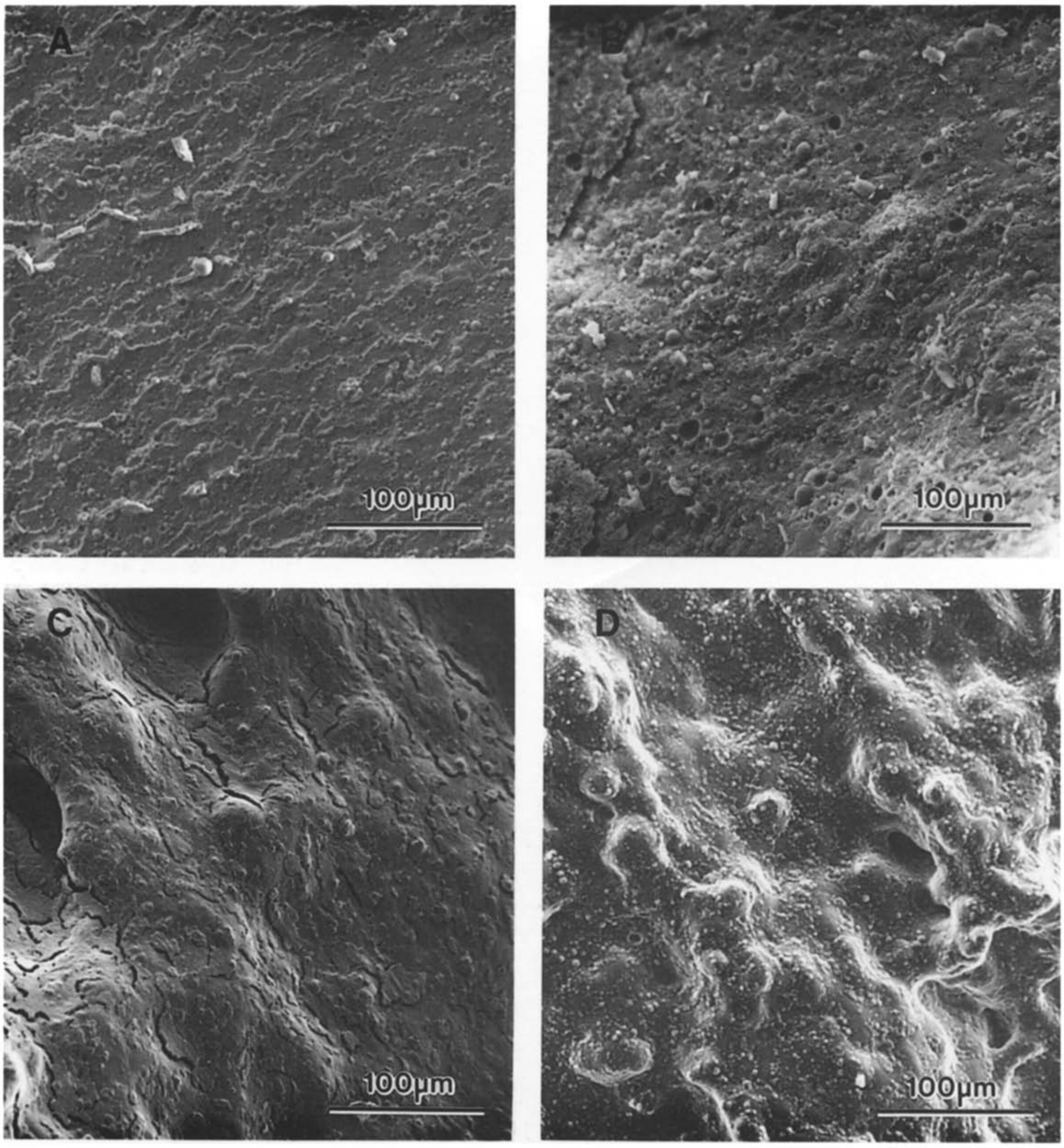

FIG. 1. Scanning electron micrographs of processed cheese analogues. MNFS = Moisture in non-fat solids. (A, B) Freeze-fracture showing internal structure; (C, D) compression fractures, frozen and freeze-etched; (A, C) 15% w/w butter oil cheese; (B, D) 15% w/w Hycoa 5 cheese.

THE ROLE OF FAT IN FOOD STRUCTURE

During mastication, food is deformed beyond the point of failure and broken into progressively smaller pieces (Green *et al.*, 1985). The way in which the food breaks down will influence texture perception. Detailed examination of the internal structure of foods and of fracture surfaces will give information about failure mechanisms which influence texture perception. Green *et al.* (1985), using scanning electron microscopy, showed that with Cheddar or Cheshire cheese the failure mechanism depended on the way in which samples had been broken. In Cheddar cheese, the fat was quite easily damaged, being squeezed to the surface during compression fracture. When Cheddar cheese was broken manually, the fracture followed a weak plane which appeared to involve the fat. They concluded that one reason for poor correlation between the sensory analysis of the texture of these cheeses and rheological measurements was the great difference in fracture mechanisms between the sensory evaluations and mechanical tests.

Another example of this research approach is in studying the role of fat in whipping cream, which should increase its volume by over 100% during whipping and form a stable, stiff product. Transmission electron microscopy of freeze-fracture replicas of whipped cream shows that the air-bubbles are stabilised by fat globules that penetrate the air-bubble/serum interface (Anderson *et al.*, 1987). In a defective cream, which had been damaged during processing, crystals of fat were found that penetrated the interface and destabilised it, giving a soft, rather runny cream (Brooker, 1990). These results explained both the visual differences and differences in rheological properties.

THE ROLE OF FAT IN SOLID-FOOD TEXTURE

To study the role of fat in more detail, a model processed-cheese system has been developed (Marshall, 1990). Cheeses are made by emulsifying fat in water at 70 °C. To this are added equal proportions of skim-milk powder and Na caseinate, lactic acid and additional water as required.

This system has been used to study the relationships between butterfat content, moisture content and texture (Marshall, 1990). Butterfat acted as a lubricant, reducing the work needed to fracture the cheeses and giving them a softer texture. In scanning electron micrographs of fracture surfaces, the fat could be seen spread out over those surfaces. The area of the surface fat was closely correlated with the square of the fat content of the cheeses.

Using this system with four fats of very different physical properties (sunflower oil, butter oil, Hycoa 5 and Coberine), the relationships between fat type, structure, rheological and sensory properties have been studied. (Hycoa 5 and Coberine are partially hydrogenated palm oils made by Loders Croklaan Ltd, London.)

The internal structure of the cheeses and the structure of fracture surfaces were examined by cryo-scanning electron microscopy (SEM) (Marshall, 1990). The internal structure of the cheeses containing different fats was similar (Fig. 1 (A, B)). The fat globules were also of approximately the same size and distribution. On SEM examination of frozen samples of surfaces produced by fracture at 22 °C, it was found that the fats behaved differently according to whether they were liquid and mostly liquid (sunflower oil, butter oil) or mostly solid (Hycoa 5 and Coberine). The soft fats were extensively damaged during compression and were squeezed out over the surface, indicating that the fractures had gone through the fat. On the other hand, when hard fats were present there was little sign of fat damage and the fractures seemed to have gone through the protein matrix and around the fat globules (Fig. 1 (C, D)).

This difference in behaviour was seen clearly in rheological compression tests (Fig. 2). As the concentration of soft fat was increased (sunflower oil or butter oil), the work to maximum stress decreased but as the concentration of the hard fats was increased (Hycoa 5 and Coberine), the work to maximum stress increased. Thus, in the latter case the hard fats were strengthening the cheese and forcing the fracture to go through the protein matrix.

The texture of these cheeses was measured by sensory evaluation using free-choice profiling (Marshall & Kirby, 1988) and the scores analysed by generalised Procrustes analysis. Analysis across the cheeses for individual assessors showed that at each fat concentration there was a tendency for the assessor to group the cheeses into those containing the soft fats and those containing the hard fats (Fig. 3 (a)).

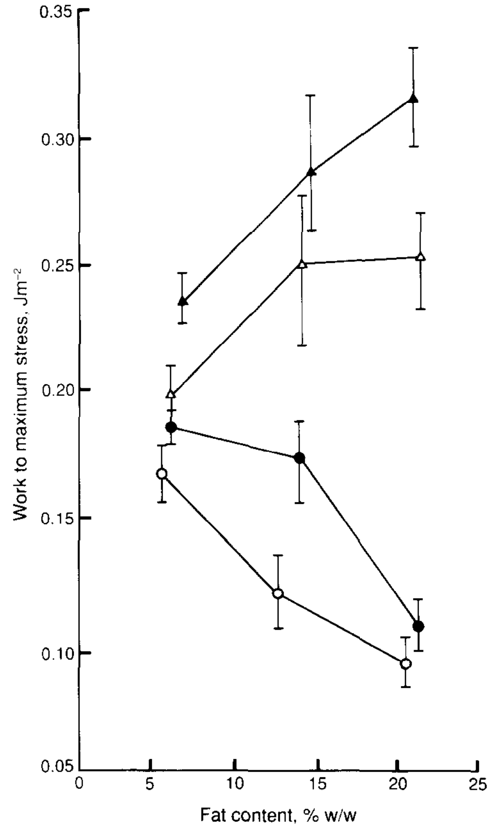

FIG. 2. Work to maximum stress of processed-cheese analogues in uniaxial compression. ○, Sunflower oil cheese; ●, butter oil cheese; △, Hycoa 5 cheese; ▲, Coberine cheese.

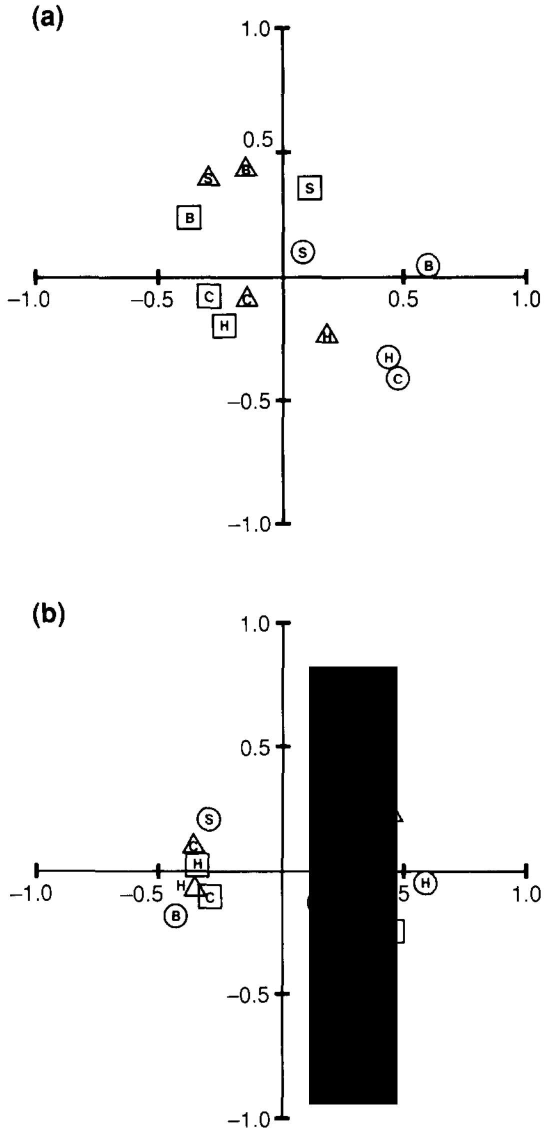

FIG. 3. Generalised Procrustes co-ordinates on the first two principal axes from analysis of sensory scores across fat type and within fat concentration. S, Sunflower oil cheeses; B, butter oil cheeses; H, Hycoa 5 cheeses; C, Coberine cheeses. ○, 5% w/w fat; △, 15% w/w fat; □, 20% w/w fat. (a) Example of results from an individual assessor. (b) Results from generalised Procrustes analysis of individuals' scores on first two principal axes.

TABLE 1. Individuals' Descriptors Correlating with the First Principal Axis from Generalised Procrustes Analysis of their Scores

Moistness	—	Stickiness
Crumbliness	—	Roughness
Greasiness	—	Slipperiness
Clamminess	—	Resistance
Smoothness	—	Dissolvability
Viscousness	—	Powderiness
Springiness	—	Smoothness
Softness	—	Breakability

Generalised Procrustes analysis of all the individual assessors' scores on the first two principal axes from generalised Procrustes analysis confirmed this tendency for the whole panel, although the results were less clear (Fig. 3(b)).

The individual descriptors that were best correlated to the first principal axis tended to describe the overall mouthfeel of the cheeses rather than fracture properties (Table 1). The generalised Procrustes scores on the first principal axis from analysis of individual assessors' data were compared with the compositional and rheological measurements by simple and multiple regression.

In four out of the eight panellists, the variation of the generalised Procrustes scores on the first principal axis was best explained by the logarithm of the fat content (Table 2). In

TABLE 2. Relationships of Composition to Scores on the First Principal Axis from Generalised Procrustes Analysis of Individual Data

Panellist no.	Physical parameter	Variance accounted for (%)	t value (df = 10)	Probability
1	log (FAT)	94·9	−14·4	< 0·001
2	log (FAT)	60·9	4·26	0·002
3	log (Hardness)	53·7	3·71	0·004
4	Moistness	95·4	15·40	< 0·001
5	log (FAT)	95·2	−14·88	< 0·001
6	FAT	95·0	14·55	< 0·001
7	Moistness	96·4	17·20	< 0·001
8	log (FAT)	96·0	16·24	< 0·001

two, the best relationship was with 'moistness' (fat content/moisture in non-fat solids); in one other, with fat hardness; and in the final one, with fat content itself.

Thus it appeared that the work to maximum stress, the Procrustes scores on the first principal axis and structural analysis divided the cheeses into two groups on the basis of the gross physical properties of the fats. The sunflower oil and butter oil spread out over the fracture surfaces, where they probably acted as lubricants, reducing the work needed to fracture the cheeses and giving a particular mouthfeel. The hard fats behaved differently in that they strengthened the cheeses and spread out after fracture only when they had reached mouth temperature and melted.

FUTURE DIRECTIONS

The work described above supports the opinion that it may be possible to understand texture perception of solid foods in terms of their material properties.

In future work it will be necessary to break the process of sensory assessment down into smaller stages. These steps should reflect some of the processes that occur during eating (Bourne, 1982) such as first bite, first chew, first 10 chews, chewing until ready to swallow, and swallowing. At each step, the assessor should describe and measure the texture. In a similar manner, the changes in composition and hence texture from one food sample to the next should be small so that the assessors will be required to measure those small differences. In addition the range of texture should be within the assessors' normal experience to ensure meaningful results (Booth, D, pers. comm. 1989).

It will be important to quantify changes in structural features during fracture with greater precision. In particular, the ability to quantify and predict the initiation and course of fracture may enable us to predict the effects of modifications in food composition on the early stages of texture perception. In conjunction with this, studies on the forces required for fracture initiation and propagation could give useful indications about the breakdown of food into smaller and smaller fragments until they reach a size suitable for swallowing. Work in this area is in progress, and has already suggested ways in which a soft fat such as butter oil can be made to behave more like a much harder one by changing the type of emulsifier (Marshall, R. J., unpublished).

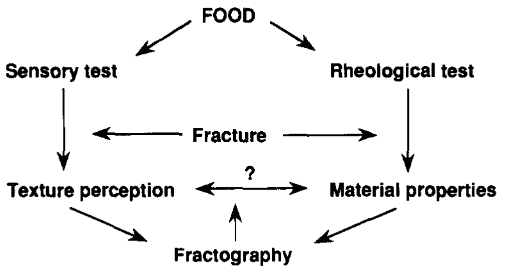

FIG. 4. Scheme showing multi-disciplinary approach to studying the role of fat in food texture.

CONCLUSIONS

The texture of a composite food depends mainly on its composition and how the components interact both with each other and with the sensory surfaces of the mouth during eating. Fat is a key component of many foods and its behaviour has a major influence on food texture. By comparing measurements from sensory, rheological and structural analysis (Fig. 4) it is possible to show how fat achieves that influence. In particular, a liquid fat can act as a lubricant lowering the work needed to break down the food and giving essential mouthfeel. Careful extension of this work using model foods with small defined changes in composition, and hence texture, will allow more precise examination of the process of texture perception. Manipulation of the physico-chemical properties of the fat should enable the manufacture of foods containing either lower levels of fat or more unsaturated fat whilst retaining fully acceptable textures.

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