Food Structure

Volume 12 | Number 1 Article 12

1993

The Stabilisation of Air in Foods Containing Fat - A Review

B. E. Brooker

Recommended Citation

Brooker, B. E. (1993) "The Stabilisation of Air in Foods Containing Fat - A Review," *Food Structure*: Vol. 12 : No. 1 , Article 12.
Available at: https://digitalcommons.usu.edu/foodmicrostructure/vol12/iss1/12

FOOD STRUCTURE, Vol. 12 (1993), pp. 115-122
Scanning Microscopy International, Chicago (AMF O'Hare). IL 60666 USA

1046-705X/93$5.00+.00

THE STABILISATION OF AIR IN FOODS CONTAINING FAT - A REVIEW

B.E. Brooker

AFRC Institute of Food Research, Reading Laboratory
Earley Gate, Whiteknights Road, Reading, Berks., RG6 2EF, U.K.

Abstract

Foods containing aqueous solutions of proteins readily foam when air is introduced into them. When fat is also present, interaction between the two components at the air/water interface may produce a stable foam with characteristic bulk properties. In the case of dairy foams (such as whipped cream), bubbles produced in the whipping process are initially stabilised by the adsorption of protein at the air/water interfaces.

Commonly encountered defects in whipping cream arise when large triglyceride crystals, formed in masses of free fat, adsorb to the air/water interface during whipping at the expense of fat globules.

In other food systems, fat crystal adsorption is part of the normal stabilizing mechanism. In cake batters produced by 'creaming' with shortening, air is held in the fat phase and stabilised by β'-crystals; however, bubbles move into the aqueous phase during cooking. Studies with batters in which the air is in the aqueous phase have shown the importance of both protein and β'-crystals in air stabilisation. The added importance of fat crystals is that they provide extra protein air/water interface for the bubbles as they expand during cooking and, thereby, help to preserve the texture of the final product.

The fat protein interactions observed at the air/water interface of several different foams, provide a unifying mechanism for the stabilisation of air in many diverse food systems.

Key Words: Adsorption, air, bubble, crystal, fat, fat globule, foam, protein.

Manuscript received February 4, 1993
Direct inquiries to B.E. Brooker
Telephone number: (44) 734 357216
Fax number: (44) 734 267917

Introduction

Proteins are amphipathic molecules whose ability to form adsorbed layers at air/water and oil/water interfaces is widely exploited to manipulate the properties of food emulsions (Kinsella and Whitehead, 1988; Tornberg *et al.*, 1990). The foaming properties of proteins are directly related to this aspect of their behaviour. With complex mixtures of proteins, adsorption can be selective and may result in an interfacial composition which may differ markedly from that of the bulk aqueous phase, especially if emulsifiers are present (Dickinson *et al.*, 1988; Courthaudon *et al.*, 1991).

Protein air/water interfaces appear by electron microscopy as dense layers whose thickness (varying from 2 - 6 nm) depends on a variety of factors including the nature and concentration of the protein. A simple protein air/water interface of this type is found in food foams, such as meringue, beer and some baked cereal products such as sponge cake. However, the stability of a protein air/water interface, and hence the characteristics of the bulk foam, may be affected by the competitive adsorption of other food components, such as lipids. Thus, the polar lipids of flour appear to contribute to good loaf volume whereas the non-polar lipids may produce detrimental effects (Daftary *et al.*, 1968; MacRitchie and Gras, 1973). Lipids, such as these, exert an important effect on foam properties, yet represent a relatively minor chemical component of the total food system. In the many cases where lipid is a major component, its interaction with the interfacial protein is of even greater consequence to the bulk properties of the foam. This review examines the role of lipid in the incorporation and stabilisation of air in food foams and considers the importance of interfacial fat-protein interactions in these processes.

Dairy Foams

Dairy foams containing fat are usually produced by the incorporation of air into creams which have been separated to various fat levels. In the case of whipped cream (about 38% fat), air bubbles in the final product are stabilised mainly by the surface adsorption of numerous fat globules. However, the initial stages of the whipping process do not involve fat. It has been demonstrated (Brooker *et al.*, 1986) that bubbles are first stabilised by the adsorption of soluble milk proteins, including β-casein, to the air/water interface (Fig. 1) and that the subsequent adsorption of fat globules during whipping is a secondary process. Indeed, even after 20 seconds of whipping, most of the bubble surface is still a layer of adsorbed milk protein and it is only when whipping is nearing completion that fat globules are the predominant components of the air/water interface (Fig. 2). However, remnants of the original protein interface are always visible between the fat globules at the bubble surface.

It is important to note that for adsorption to occur, the cream must be stored at a low temperature in order to allow the globular fat to reach the correct solid/liquid ratio. Without this conditioning process, involving the crystallization of triglycerides and the reduction in the proportion of butter oil, bubbles are destabilised by the adsorbing globules. In such a case, butter oil from adsorbing globules spreads at the air-water interface, causes local thinning of the protein film and eventually bubble collapse (Prins, 1986).

Using freeze fracturing, Buchheim (1978) found that globule adsorption to the air bubbles results in partial loss of the globule membrane so that a portion of the fat comes into direct contact with the air and protrudes slightly into the bubble (Fig. 2). This is possible in conditioned cream because the triglyceride crystals hold the uncrystallised, liquid butter oil in place by capillarity and prevent its spreading at the interface. The process of globule adsorption involves the fusion of the protein air/water interface of the bubble with the oil/water interface of the fat globules and has now been observed by several authors (Schmidt and van Hooydonk, 1980; Brooker *et al.*, 1986; Anderson *et al.*, 1987; Anderson and Brooker, 1988). These studies, which included the *en face* examination of freeze fractured bubbles by low temperature scanning electron microscopy (cryo-SEM), also showed very clearly the amount of residual interfacial protein between the globules in stabilised bubbles (Fig. 3).

This fat-protein structure of the air/water interface is one that is common to other dairy foams (such as ice cream, mousse and some toppings) containing milk proteins and a dispersed fat phase (Fig. 4). All of the available evidence suggests that the same mechanism of interfacial lipid-protein interaction is responsible for the incorporation and stabilisation of air in all of these products. Earlier ideas that air bubbles in whipped cream (Graf and Muller, 1965) and ice cream (Berger *et al.*, 1972a, 1972b) are lined by a layer of oil from the fracture of fat globules at the air interface have now been superceded (Buchheim and Dejmek, 1990). In the case of ice cream, the smooth protein/air interface between adsorbed fat globules was believed to be a thin layer of oil.

It is clear from a consideration of a variety of aerated oil-in-water food emulsions that air stabilisation is similar to that described for whipped cream, although the number of adsorbed fat droplets is variable and depends on the fat content.

Figure 1. Part of the protein air/water interface (arrow) of a milk foam. Casein micelles (C) are attached to the aqueous side of the interface.

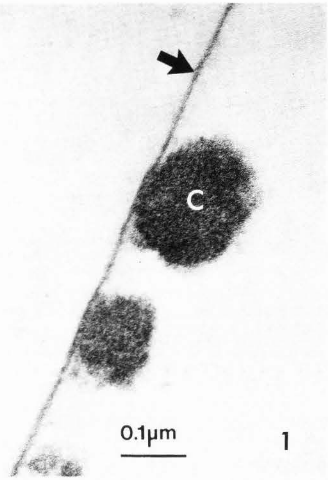
Figure 2. Cream whipped for 20 seconds showing the adsorption of fat globules to the protein air/water interface (small arrows). Notice the bulging of the fat globules into the air bubbles and the start of globule coalescence (large arrow). The white, thread-like structures inside globules represent triglyceride crystals.

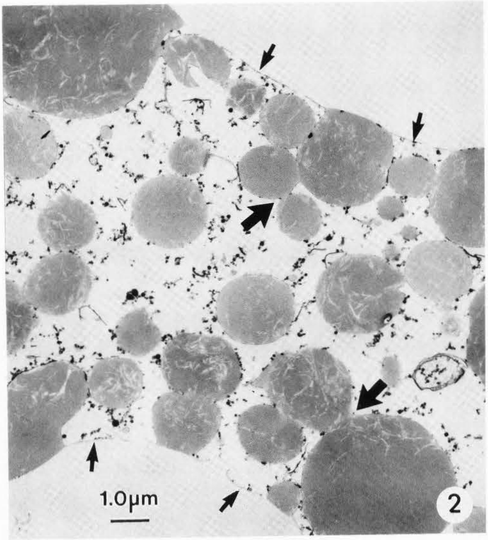
The elucidation of the mechanism of bubble stabilisation in normal whipped cream has been followed by structural studies to identify the interfacial changes that must occur in those creams that have a tendency to collapse after whipping or that do not whip normally. Studies using cryo-SEM led Anderson *et al.* (1987) and Anderson and Brooker (1988) to attribute instability of whipped creams to fat globule aggregation caused by mechanical damage to the cream during separation. However, since that time it has been found necessary to use freeze fracturing in conjunction with transmission electron microscopy in order to obtain sufficient spatial resolution to observe the subtle changes that take place in the interfacial structure of defective compared with normal foams (Brooker, 1990).

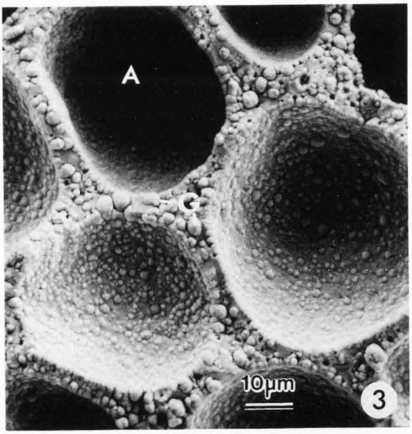
This same work has shown that small crystals of fat (triglyceride) are occasionally found adsorbed to the protein air/water interface of normal whipped cream. These crystals originate from the droplets of free fat that are produced when fat globules are mechanically damaged during processing and, therefore, must be present in small numbers in all normal creams; the rupture of some milk fat globules and the release of free fat in the course of normal separation procedures has been discussed at length by Rothwell (1966) and Foley *et al.* (1971).

In contrast to this, the defective whipping creams have conspicuous large bodies of free fat distributed throughout the aqueous phase which doubtless arise by inappropriate processing and handling of the cream, as discussed above. When these creams are whipped, numerous, very large crystals of fat are found adsorbed to the air/water interface of bubbles and they are able to inhibit normal fat globule adsorption during whipping (Fig. 5). The large size of the fat crystals (relative to the diameter of the largest fat globules) arises because crystal growth can continue uninhibited in the surrounding butter oil at the low ambient storage temperatures. Together with the destabilising effect of free liquid fat on bubble formation (Prins, 1986), the inhibition of globule adsorption and the corresponding loss of fat globule cross-linking between bubbles, accounts for the poor whipping properties of these creams.

Given that triglyceride crystals for adsorption are derived from bodies of free fat, the mechanism by which they reach the air/water interface and adsorb to it is not







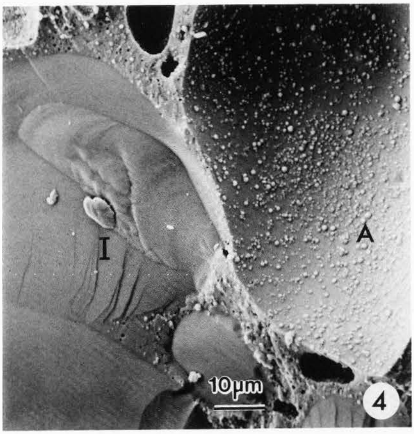


Figure 3. Whipping cream prepared by cryo-SEM showing the inside surface of several air bubbles (A). The bubbles are stabilised by numerous fat globules (G) adsorbed to the air/water interface.

Figure 4. Frozen and fractured ice cream showing ice crystals (I) and an air bubble (A) to whose interface is adsorbed numerous small fat globules. The smooth area between the globules corresponds to the protein air/water interface. Cryo-SEM.

clear, but two possibilities exist. Either **a**) the crystals are sheared from the surface of the lumps of free fat during whipping and adsorb to the protein air/water interface; or **b**) the bodies of free fat adsorb to the air/water interface and, due to their large size, are soon detached by shearing forces, leaving triglyceride crystals attached to the air bubbles; the surface forces holding a mass of free fat are proportional to its radius, whereas the shearing forces are proportional to its radius squared. The ability of masses of free fat (containing fat crystals) to attach to air bubbles, and to remain attached at the end of whipping, is shown in the confocal micrograph of a defective whipped cream in Fig. 6.

It is predictable from the known behaviour of lipid dispersions in aqueous solutions of proteins, that bodies of free fat in cream should be covered in an interfacial layer of adsorbed milk protein. It follows that interaction of this lipid with air bubbles, either by route a) or b) as discussed above, must involve an interfacial protein/protein interaction of the kind already discussed as part of the mechanism for normal fat globule adsorption.

Toppings

In many other food systems, fat crystal adsorption to a protein air/water interface is part of the normal stabilizing mechanism of air bubbles. The work of Buchheim *et al.* (1985) and Krog *et al.* (1987) on whippable emulsions (toppings) is an extreme case. They studied experimental spray-dried toppings after reconstitution with water and showed that there was a structural change in the fat phase from a dispersed globular state in the powder to a network of crystal platelets in the reconstituted emulsion.

When these products were whipped, the bubbles in the final product were either largely or completely stabilised by adsorption of the crystal platelets to the interface, depending on the emulsifier used. Although there appeared to be a minimal involvement of interfacial protein in the final topping, its very presence makes it likely that with these products also there is a transient air/water interface of protein that is more or less displaced by the adsorbing fat crystals. It is interesting to note that part of the fat phase in the topping powder was in a supercooled state; the main factors responsible for this supercooling were the small particle size of the fat globules and the lipid-protein interactions of the sort observed by Trumbetas *et al.* (1979) using pulsed nuclear magnetic resonance.

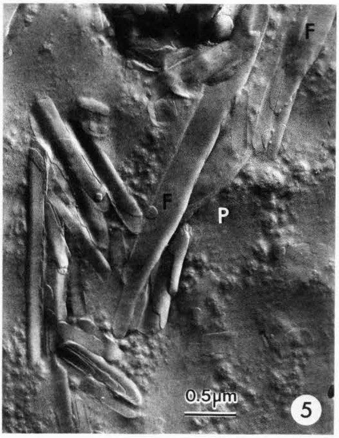
Shortenings and Batters

A similar stabilisation of air bubbles by triglyceride crystal platelets is found in shortenings. However, these are mixtures of liquid and crystalline fats but do not contain an aqueous phase. It is evident, therefore, that when air is beaten into them, the resulting air bubbles must be stabilised solely by lipid components. Hoerr (1960) referred to the practice of plasticizing fats by beating air into them during crystallization in order to produce smoother and more uniform products. He was also the first to appreciate that in this aeration process, the polymorphic form of the crystalline fat affected the way in which air was incorporated. Thus, crystals of the β'-polymorph allowed the stabilisation of many small bubbles whereas the larger β-crystals incorporated relatively little air in the form of a few large bubbles. Using electron microscopy in conjunction with freeze fracturing, it has now been shown that bubbles are dispersed in the continuous oil phase of shortenings and that they are stabilised by tangentially oriented β'-crystals at the air/oil interface (Berger *et al.*, 1979) (Fig 7.).

These aeration properties have a direct effect on their use as shortenings in the production of batters because the number of air bubbles incorporated into batters during mixing (and persisting in the baked product), parallels the aeration behaviour of the different polymorphs described above (Hoerr, 1960). Using the 'sugar batter' process of batter aeration, Meara *et al.* (1974) showed that after blending sugar into the shortening ('creaming'), the air bubbles are similarly stabilised with adsorbed β'-fat crystals. According to Meara *et al.* (1974), the reason why small β'-crystals were able to incorporate air so well was because smaller crystals could arrange themselves around the interface of bubbles more easily than the larger β-polymorph.

It is now widely believed that in a finished batter (containing flour, eggs, sugar, and shortening), most of the air bubbles are still held in the fat phase at room temperature (e.g. see Shepherd and Yeoll, 1976). During heating, many of them move from the fat into the aqueous phase where, it is assumed, the bubbles are stabilised by egg protein. However, the bubble apparently takes a layer of fat with it which can still be seen in the cooked cake but whose spatial relationship to the true air interface is not known. The significance of some of these complex interfacial events to the formation of a stable foam structure in the cooked product is not understood and these phenomena have not yet been examined in detail by electron microscopy.

However, some recent work with experimental batter mixtures has shed some light on these problems. The batters were prepared by the 'all in one procedure' in which the ingredients of egg, flour, sugar, and shortening (with an added emulsifier) were mixed together in one simple process (Brooker, 1993, submitted); this method of mixing is increasingly used both industrially and domestically. In contrast to the 'creamed' batters described above, this type of mixture produces an aqueous phase aeration and allows the structural elements at the air/water interface to be identified more easily in both the raw batter and during cooking. During the mixing of these raw batters, the shortening becomes dispersed as a fine, protein stabilised emulsion. From the surface of the oil droplets, β' fat crystals project into the aqueous phase and have their surface covered with a thin layer of adsorbed protein. Until the shortening is completely dispersed, air bubbles incorporated into the



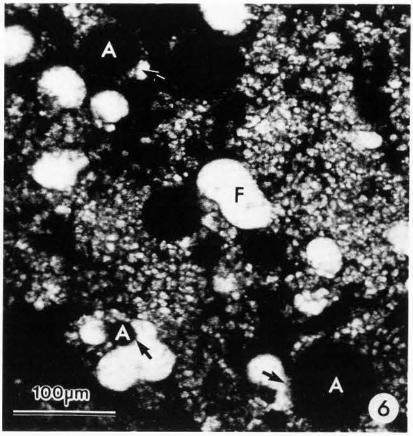


Figure 5. Part of the inside surface of an air bubble from a defective whipped cream showing elongate fat crystals (F) adsorbed to the protein air/water interface (P). Frozen and fractured.

batter are stabilised solely by an air/water interface of adsorbed egg proteins. As mixing proceeds, triglyceride crystals come into contact with the bubbles and adsorb in large numbers to their surface by a process which involves a protein/protein interaction of the type described above for fat globules in whipped cream (Fig. 8). This process of crystal ejection depends on the presence of emulsifier in the shortening and is reminiscent of the phenomenon described by Boode (1992) from simulated milk fat.

The important of crystalline fat to the incorporation of air in batters can be seen in Fig. 9. Batters prepared with no shortening contain many bubbles which are stabilised by egg protein alone; the addition of shortening changes the structure of the air/water interface and has a marked effect on batter aeration by greatly increasing the number of smaller air bubbles in the size distribution.

It is important to note that once crystal adsorption has occurred, the protein air/water interface of the bubble is continuous with the protein layer on the fat crystals; the crystals are then in direct contact with the air (Fig. 10). This mechanism for fat adsorption helps explain many earlier observations on the cakes produced from 'creamed' batters that fat is able to pass from the aqueous phase to the air phase of the batter.

Fat adsorption in this way has a further consequence for bubble stability during cooking as the air expands and the bubbles begin to increase in volume. When the batter is heated, the fat crystals melt, flow

Figure 6. Confocal laser scanning micrograph of a defective whipped cream treated with Nile Blue and showing bodies of free fat (F) attached (at arrows) to air bubbles (A). Numerous small fat globules are visible in the background. From a bulk sample 20 mm x 20 mm x 5 mm thick.

Figure 7. An air bubble from a plasticised shortening whose surface is stabilised by β' fat crystals (F). The lipid matrix is composed of a network of β' hardened palm oil crystals entrapping rapeseed oil.

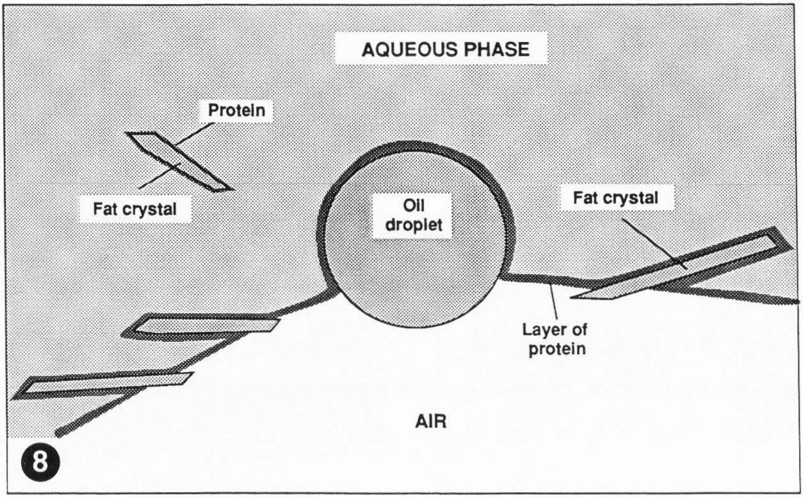


Figure 8. Diagram of part of the bubble in a cake batter showing the relationship of fat crystals and adsorbed protein at the air/water interface. Droplets of oil from the shortening occasionally adsorb but do not affect bubble stability.

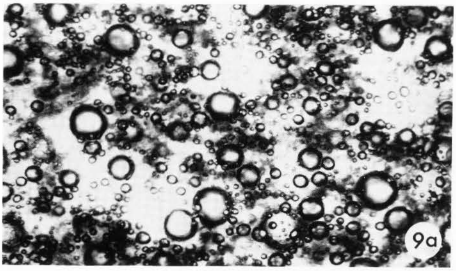
along the inside surface of the bubble, and move away from the protein layer of the original crystal/water interfaces of the many adsorbed crystals (Fig. 8). The requirement for such a mechanism is self-evident and was realised earlier by Shepherd and Yeoll (1976), who drew attention to the necessity for bubbles to support rapid expansion and not undergo rupture before the cake batter is heat-set. However, a satisfactory mechanism by which this might be achieved has not previously been proposed.

These observations help to clarify interfacial events during cooking and explain the importance of crystalline fat for the successful production of well-aerated cake. However, further work is in progress to integrate these results into a general mechanism for the incorporation and stabilisation of air in other cereal products in which lipids are believed to be important functional ingredients. For example, studies of the expansion of doughs during baking as a function of time and temperature have shown that those containing shortenings continue to expand during baking for a longer time than doughs without added lipid (Junge and Hoseney, 1981). Also, bread baked by the Chorleywood process contains hardened fat to prevent the bread collapsing in the oven. Although no detailed microscopical study of the behaviour of fat at the air/water interface of doughs has been published, it is tempting to suggest that the function of the crystalline fat is related to that described here for cake batters. No other hypothesis has been proposed to provide a clear explanation for the mechanism by which hard fats are able to improve final loaf volume.

Concluding Remarks

These examples demonstrate some of the ways in which lipid (in the form of dispersed oil droplets or fat crystals), contributes to the incorporation and stabilisation of air in some food foams. The mechanism of air stabilisation involves the adsorption of particulate lipid at the air/water interface, and this in turn requires an appropriate balance of interfacial free energies such that particles of lipid are wetted preferentially by the continuous phase. Thus, for foams containing an aqueous as well as a lipid phase, it is the contact angle between the three interfaces, i.e., lipid water, lipid/air and air/water, that defines the ability of the lipid to stabilise (or destabilise) the foam. Increasing the lipid/water or air/water interfacial tension increases the strength of attachment of lipid to the air bubbles and increases stability. In practice, this can be achieved either by manipulating the nature of the interfacial protein or by the use of appropriate emulsifiers.

One general principle to emerge from the study of multiphase foams is that lipid interfacial adsorption is a secondary process and occurs only after the air/water



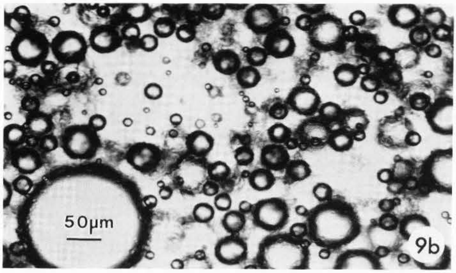


Figure 9. The effect of shortening on the size distribution of air bubbles in cake batters. Micrographs taken at identical magnification. (**a**) Air bubbles in cake batter prepared from sugar, flour, egg, and shortening. (**b**) Cake batter identical to that in (a) but containing no shortening.

interface has been stabilised, albeit transiently, by the surface active proteins. The difficulty of explaining the adsorption of hydrophobic, naked lipid to a protein air/water interface is overcome by the realisation that in some systems at least, viz. whipped cream and batters, the dispersed lipid phase is coated with adsorbed protein. The adsorption of lipid occurs when this adsorbed layer makes contact with and coalesces with the protein air/water interface of the bubble. In this way, the lipid is brought into direct contact with the air and helps to stabilise the bubble.

References

Anderson M, Brooker BE, Needs EC (1987) The role of proteins in the stabilization/destabilization of dairy forms. In: Food Emulsions and Foams. Dickinson E (ed.). Royal Society of Chemistry, London, 100-109.

Anderson M, Brooker BE (1988) Dairy foams. In: Advances in Food Emulsions and Foams. Dickinson E, Stainsby G (eds.). Elsevier Applied Science, 221-255.

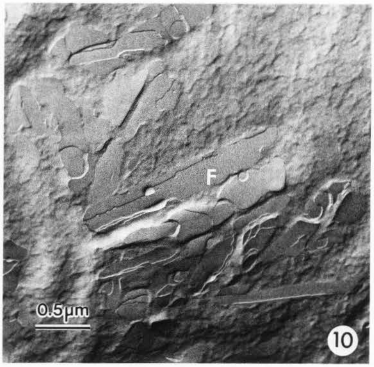


Figure 10. Part of the inside surface of a freeze fractured air bubble from an uncooked cake batter showing adsorbed fat crystals (F) from the shortening in contact with the air. The surrounding surface is the protein air/water interface. Compare to Fig. 8.

Berger KG, Bullimore BK, White GW, Wright WB (1972a) The structure of ice cream - Part 1. Dairy Industries **37**, 419-425.

Berger KG, Bullimore BK, White GW, Wright WB (1972b) The structure of ice cream - Part 2. Diary Industries **37**, 493-497.

Berger KG, Jewell GG, Pollitt RJM (1979) Oils and fats. In: Food Microscopy. Vaughan JG (ed.). Academic Press, London, 445-497.

Boode K (1992) Partial coalescence in oil-in-water emulsions. Ph.D. Thesis, Wageningen Agricultural University, Netherlands, 39-54.

Brooker BE (1990) The adsorption of crystalline fat to the air/water interface of whipped cream. Food Structure **9**, 223-229.

Brooker BE, Anderson M, Andrews AT (1986) The development of structure in whipped cream. Food Microstructure **5**, 277-284.

Buchheim W (1978) Mikrostruktur von geschlagenem Rahm (Microstructure of whipped cream). Gordian **78**, 184-188.

Buchheim W, Barford NM, Krog N (1985) Relation between microstructure, destabilization phenomena and rheological properties of whippable emulsions. Food Microstructure **4**, 221-232.

Buchheim W, Dejmek P (1990) Milk and dairy type emulsions. In: Food emulsions. Friberg S (ed.). Marcel Dekker, New York, 203-246.

Courthaudon J-L, Dickinson E, Matsumura Y, Williams A (1991) Influence of emulsifier on the competitive adsorption of whey proteins in emulsions. Food Structure **10**, 109-115.

Daftary RD, Pomeranz Y, Shogren M, Finney KF (1968) Functional bread-making properties of wheat flour lipids. II The role of flour lipid fractions in bread-making. Food Technology **22**, 327-330.

Dickinson E, Murray BS, Stainsby G (1988) Protein adsorption at air-water and oil-water interfaces. In: Advances in Food Emulsions and Foams. Dickinson E, Stainsby G (eds.). Elsevier Applied Science, 123-162.

Foley J, Brady J, Reynolds PJ (1971) The influence of processing on the emulsion stability of cream. Journal of the Society of Dairy Technology **24**, 54-58.

Graf E, Muller HR (1965) Fine structure and whippability of sterilized cream. Milchwissenschaft **20**, 302-308.

Hoerr CW (1960) Morphology of fats, oils and shortenings. Journal of the American Oil Chemist's Society **37**, 539-546.

Junge RC, Hoseney RC (1981) A mechanism by which shortening and certain surfactants improve loaf volume in bread. Cereal Chemistry **58**, 408-412.

Kinsella JE, Whitehead DM (1988) Emulsifying and foaming properties of chemically modified proteins. In: Advances in Food Emulsions and Foams. Dickinson E, Stainsby G (eds.). Elsevier Applied Science, 163-188.

Krog N, Barford NM, Buchheim W (1987) Protein-fat-surfactant interactions in whippable emulsions. In: Food Emulsions and Foams. Dickinson E (ed.). Royal Society of Chemistry, London, 144-157.

MacRitchie F, Gras PW (1973) The role of flour lipids in baking. Cereal Chemistry **50**, 292-302.

Meara ML, Evans GG, Jewell GG, Davies DP (1974) Studies on creaming power of fats. British Food Manufacturing Industries Research Association Research Report 204.

Prins A (1986) Some physical aspects of aerated milk products. Netherlands Milk and Dairy Journal **40**, 203-215.

Rothwell J (1966) Studies on the effect of heat treatment during processing on the viscosity and stability of high-fat market cream. Journal of Dairy Research **33**, 245-254.

Schmidt DG, van Hooydonk ACM (1980) A scanning electron microscopical investigation of the whipping of cream. Scanning Electron Microscopy **1980**;III, 653-658.

Shepherd IS, Yeoll RW (1976) Cake emulsions. In: Food emulsions. Friberg S (ed.). Marcel Dekker, New York, 215-275.

Tornberg E, Olsson A, Persson K (1990) The structural and interfacial properties of food proteins in relation to their function in emulsions. In: Food Emulsions. Larsson K, Friberg SE (eds.). Marcel Dekker, New York, 247-326.

Trumbetas J, Fioriti JA, Sims RJ (1979) Study of lipid-protein interaction using pulsed NMR. Journal of the American Oil Chemist's Society **56**, 890-893.