Fat Bloom

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Dr. Eugene Hammond and Susan Gedney are research scientists based at United Biscuits Group Technical research laboratories in High Wycombe. Their article covers the following topics:

1. Introduction

Fat bloom is a common problem in the confectionery industry. It is most often seen on chocolate, but can also appear on the surface of biscuits. The problem can cause very significant product losses. This is not because there is a contamination or specific quality issue. It is mainly because the visual characteristics become unacceptable, due either to loss of gloss or to the appearance of a white "frosting" at the surface of the product. The white frosting (Figure 1) is sometimes mistaken for mould growth but quite definitely is not. It is a surface re-crystallisation of fat caused generally by migration.

Figure 1: White "beta-form" bloom ("frosting") on the chocolate of a half-coated biscuit

A more severe situation in chocolate can occur after some time, where the chocolate becomes grainy, crumbly and with no gloss or sensory appeal (Figure 2). This happens throughout the bulk of the chocolate material and is not just a surface phenomenon (Figure

3).

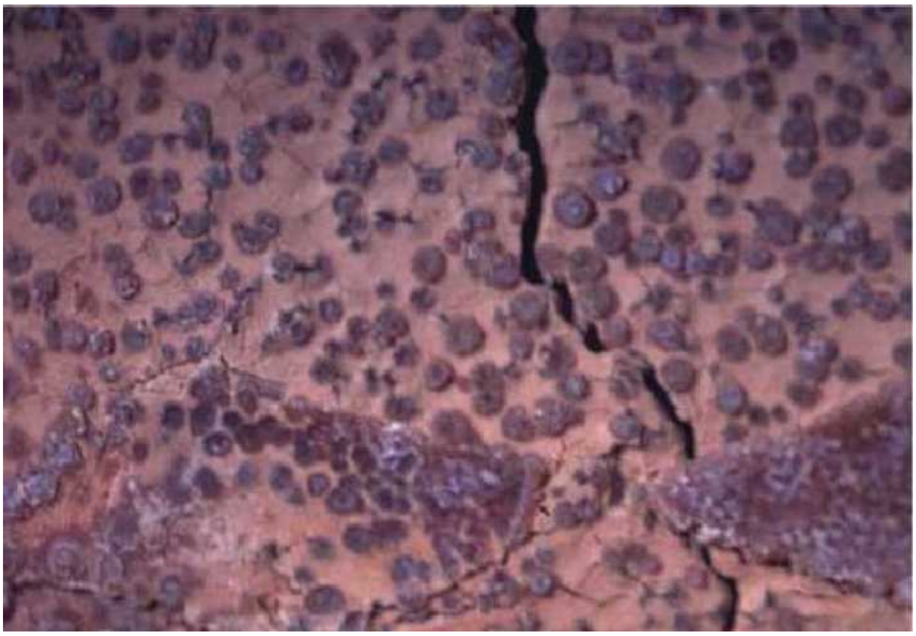

Figure 2: Severe bloom caused by Form VI crystal growths on the surface of chocolate

From what we have said above it becomes plain that there are at least two bloom effects. The bloom that is a characteristic of chocolate (Figures 2 and 3) may be termed Form VI bloom. The bloom shown in Figure 1 on the surface of chocolate can also appear on the surface of biscuits and even in semi-solid fats such as butter and fat spreads. This type is caused by a re-crystallisation of fat and is often accompanied by a change in crystal morphology. This type may be loosely called "beta-form" bloom. It is important to understand also that there is more than one mechanism at work. Food products are not static entities, they are quite dynamic and this creates partly the phenomenon of shelf life. The properties that we have to consider are, in the main, thermodynamic ones. Multiple-phase foods, such as butter-cream-filled biscuit bars with a chocolate coating, create conditions where thermodynamic change is positively driven. Entropy is not a term just for physicists, because in making such foods the processes must address free energy change if a stable, long shelf life is to be achieved. The manufacturing process must attempt to achieve a stable low energy state for the components. If it does not then you end up, for instance, with partially crystallised fat in the insulated environment of palletised finished goods. Why is this a problem? We will explain this in the following text.

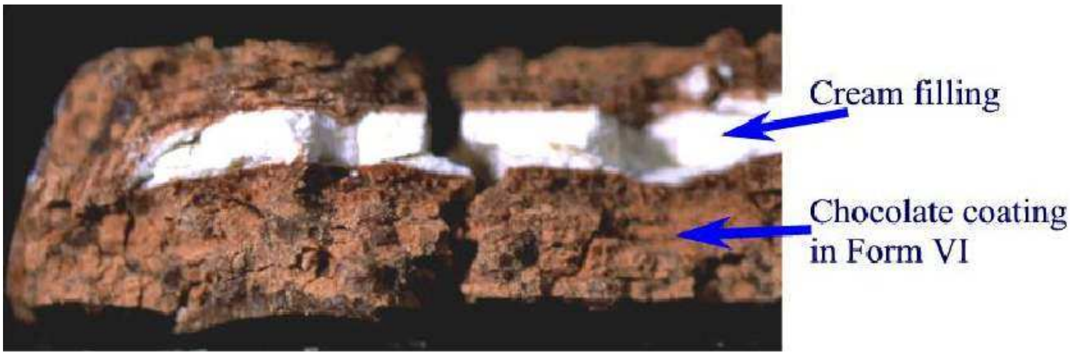

Figure 3: Form VI bloom in chocolate causes major structural change

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2. Fat Crystallisation

All natural fats are mixtures of triacylglycerols (TAG). Each pure individual TAG will have a different crystallisation temperature. However, when mixed this causes the fat to have a wide range of temperature over which crystallisation occurs. Thus you obtain the phenomenon of solid/liquid ratios in fat mixtures. These ratios can be determined using pulsed nuclear magnetic resonance (pNMR) and some data is shown in Figure 4. It can be seen from this data that, if a product is made using one or more of the fat mixtures and then displayed for sale, the temperature of the display area will affect the state of the fat in the product. Thus as temperature cycles, so does the liquid/solid fat ratio. More importantly, the ratio will often be different in each fat phase at the given temperature, creating imbalances across the different food matrixes, e.g. biscuit dough, cream filling and chocolate coating in a biscuit snack. We shall come back to this situation.

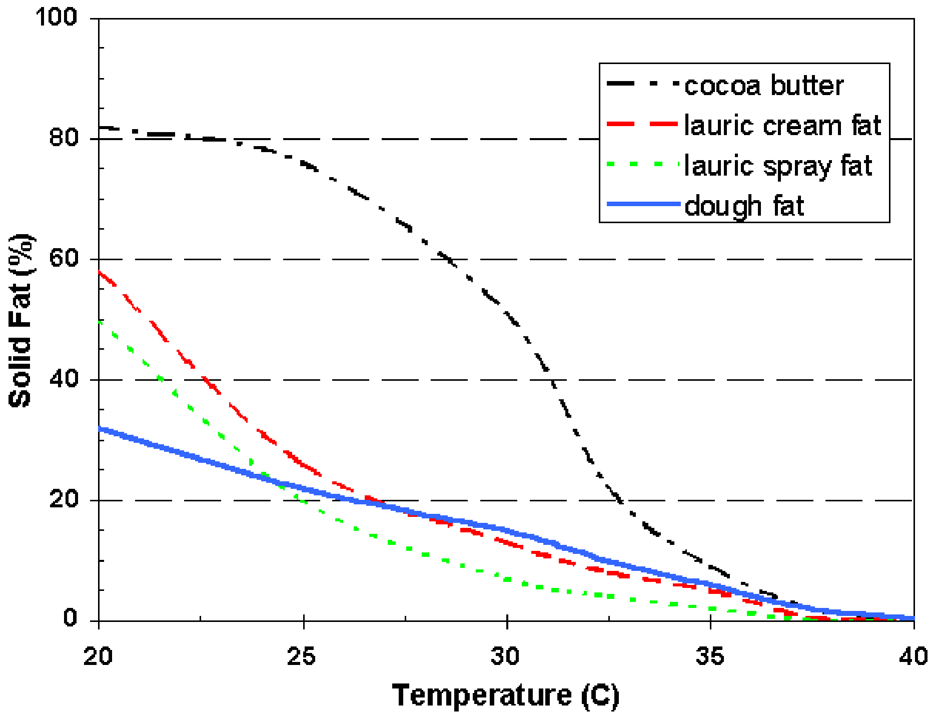

Figure 4: Solid Fat Content by pulsed NMR - typical Values

Crystallising fat systems are usually polymorphic. In most cases this is represented by 3 crystal forms termed α (alpha) , β' (beta prime) and β (beta), in increasing thermodynamic stability and increasing melting point. Not all fats can move freely from α to β because this depends on the ability of molecules to pack closer together. Some can, like cocoa butter; some cannot, like Salatrim (Benefat) which stays in the α form. There is further complexity in that certain TAG types (cocoa butter is very rich in these symmetrical TAGs which have an unsaturated fatty acid at the middle position) create the possibility for up to 6 crystal forms. The chocolate tempering process is designed to stimulate cocoa butter to crystallise in Form V. This process involves maintaining the temperature at around 29C-31C after a controlled cooling process.

Crystallising fat gives up heat energy (its heat of crystallisation). As the process progresses to more stable forms a certain amount of heat energy might be required to begin the process. Thus if a fat has reached β' and is then stored at, say, less than 20C, it is unlikely to progress to β form, unless it is heated to above 25C. This point brings us back to two issues mentioned above: cycled temperature storage and palletised storage.

Cycled temperature storage applies significant energy stress to a product. This often results in a change of crystal form. In addition, during cycling temperatures, the crystalline fat can begin to separate from the liquid phase and undergo individual changes. For palletised storage of poorly cooled product, the crystallising fat yields heat that cannot escape due to the insulating nature of palletised boxed products. This excess heat can raise the internal temperature by 2-3C. This can be sufficient to cause fat/chocolate melting and recrystallisation.

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3. Liquid Fat Migration

In a crystallised fat, the liquid fat component is dispersed in and around the solid crystal clumps. The mobility of this liquid will to some extent depend upon the three-dimensional structure of the solid crystal network. At a given temperature, the liquid component will have a certain composition. As the temperature rises the amount of liquid fat will increase and its TAG composition will change.

In a single-matrix system, the consequence of this change may be nothing. Alternatively, it may trigger certain TAGs to separate or fractionate from the main bulk of the fat. This will lead to the growth of larger crystals over time that may be in the β form.

In a system with more than one matrix, each containing a different fat, the picture becomes complex. There are different liquid/solid ratios, maybe different total fat contents and different TAG compositions. All these points apply their own thermodynamic pressure for the liquid fat components to move or migrate between the matrixes. Although this fat migration may not be a problem, it usually does create problems.

As the liquid fats move between matrixes they mix with other liquid fat phases and thus change their composition. This may cause a change in the solid fat solution, i.e. more solid fat might dissolve at a given temperature, causing softening. In addition, the balance of the solution composition might change sufficiently to make other TAGs less soluble, causing them to crystallise out. The effect of temperature cycling must also be superimposed on this process. Different effects can be seen in some products when they are stored at different constant temperatures (e.g. 22C or 25C) because the composition of the liquid fat phase varies with temperature.

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4. Bloom Types

We have described above a number of dynamic processes that happen in products containing significant amounts of TAG. So how are these related to fat bloom? The visual effect of fat bloom is caused by crystal growth or a change in the crystal morphology after the product has been made (i.e. during shelf life). Let us now consider the Form VI and beta-form types of fat bloom.

Figure 1 shows a white frosted, beta-form bloom growth on the surface of chocolate. The crystals that are growing look (in close-up) very like diamond clusters. The finer structure is shown in Figure 5. This contrasts greatly with the leaf-like structures of classic Form VI bloom shown in Figure 6. This beta-type bloom is migration related and can be particularly bad where the migrating components come from a palm oil based dough fat. This type of bloom is rich in symmetrical TAGs of the POP and POSt type (P = palmitic acid, O = oleic acid, St = stearic acid). Form V to Form VI inhibitors will not stop this bloom occurring because it is a shift in solid solution caused by the migrating palm oil TAGs. It is interesting to note that if the chocolate-coated product is stored at a constant 22C this bloom is predominant. However, if the storage temperature is a constant 25C then Form VI bloom occurs.

Figure 5: Beta form bloom crystals on surface of chocolate (these can also appear on biscuits)

The white frosting can be generated directly on the surface of high-fat baked goods, such as biscuits through fat separation and crystal growth. These biscuits can show the effect whether half coated with chocolate or not. The effect is more prevalent where palm oil is a major part of the fat blend in use. It is a consequence of the TAG composition of palm oil, which contains significant amounts of POP/POSt and PPP. Palm oil readily fractionates under certain conditions to yield fast growing crystals in the β form. This problem can be caused by over-cooling (shock-cooling) the product as it leaves the oven and packaging point. A certain amount of α crystal is formed and an unstable situation exists. Transformations over the next 24 hours often yield a bloomed surface. This bloom is not always permanent and can sometimes be removed by warming the product to 25C for a short period of time. A similar effect can be caused in the biscuit where a chocolate coating or inclusion (e.g. chocolate chips in cookies) may act as a very efficient "sink", via migration, for the liquid fat fraction. The consequence in time is a bloomed visual effect as the more solid TAGs recrystallise with growth of crystal size.

Another effect caused by overheating the surface of, for example a biscuit, is that the fat melts and liquid fat is drawn to the surface. This then cools quiescently and forms large crystal clumps that appear as bloom. This bloom is usually permanent. Such effects are caused, for example, by the hot plate, pack, end sealers overheating the packaging. The end biscuits in a pack then exhibit a "staining" effect, caused by large fat crystals.

Figures 2 and 3 show a particularly severe case of Form VI bloom in chocolate. The chocolate bar had a fat-cream filling and had been exposed to temperatures cycling between 18C and 28C over a period of 8 weeks. The chocolate has completely destabilised and the surface is covered with crystal growths. More particularly the whole structure has transformed to Form VI (confirmed using X-ray diffraction) and has become open, fragile and powdery. This type of bloom can be reduced, but not always eliminated, using Form V to VI inhibitors.

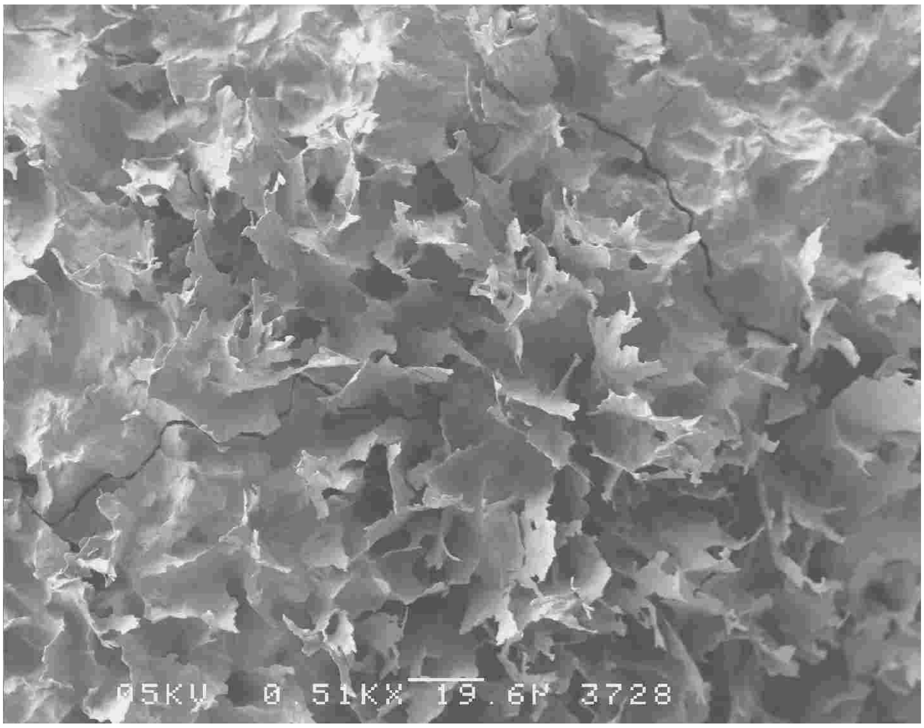

Figure 6: Leaf-like structures of classic Form VI bloom

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5. Bloom Prevention

The title of this section is easy to write, the doing of it is not so easy. As we said earlier, foods are dynamic systems and undergo significant change during shelf life. If we are to prevent bloom then we have to address thermodynamic change. That means either ensuring the food product has a low free energy state (i.e. is stable to further physical change), or, introducing some means of interrupting change by perhaps blocking it.

The former method is used extensively by the fat spreads and chocolate industries. The product is made under optimum temperature conditions to ensure that the correct fat crystal form is generated. The product is then given sufficient time to "temper" under controlled temperature storage before it is fully packaged, boxed and palletised for delivery. This regime ensures that, for spreads the β' fat crystal form predominates and is stabilised, while for chocolate, the latent heat of crystallisation is removed below 25C to ensure a stable Form V crystal network is created. This approach does, to a large extent, assume that the product will not undergo large, post-production, temperature fluctuations during transport, sale and use/storage by the consumer.

However, it is a fact of life that time costs money and any means of speeding up product flow and increasing volume is enthusiastically sought by manufacturers (or at least by their management!). In addition, environmental temperature for product storage can be advised but not always ensured. In these situations some means of blocking crystal change can be advantageous. Milk chocolate contains a significant amount of butterfat and, because butterfat creates a strong eutectic with cocoa butter, the resultant product is much softer than plain chocolate. Milk chocolate rarely if ever undergoes Form VI bloom. The reason for this is the composition of butterfat contains a large range of TAG structures and molecular weights. This is due to the presence of significant amounts of fatty acids from C4 to C14. These serve to block the move from Form V to Form VI because, as they co-crystallise with cocoa butter TAG, the packing density of the crystals does not permit the thermodynamic change. The butterfat TAG also cause a change in the solid solution and thus a softer product. Both these effects reduce the incidence of bloom. This action of butterfat can (and is) harnessed to reduce the occurrence of bloom in plain chocolate. Butterfat can be added at a low level where softening of the chocolate is not significant but the effect on crystal form change is very significant.

The blocking of V to VI crystal form change in chocolate with butterfat is accompanied by a strong eutectic; in addition butterfat currently costs more than cocoa butter. Partly in response to this, some of the special (confectionery) fat suppliers have designed bloom inhibitors as vegetable fat additives to chocolate. It is important to recognise that these additives have to form part of the current legislated limit of 5% added vegetable fat in chocolate. However, the composition of these fats is such that a range of TAG structures containing fatty acids from C10 to C18 is introduced into the cocoa butter. These act to inhibit the re-crystallisation of cocoa butter TAG in Form VI.

Form V to Form VI inhibitors such as described above do not stop the beta-form bloom. This is because beta-form bloom is mainly a consequence of re-crystallisation and crystal growth following transformation from β' fat crystal. This type of bloom is much more difficult to address and arguably is much the most prevalent. Prevention here is one of understanding the product makeup, the process temperatures and times, and the compatibility of adjacent fats where the product has more than one component. This last point is imperative when considering shelf life of the product ex factory.

Compatibility of adjacent fats is necessary because fat migration will take place. Non-compatibility will cause changes in the fat phase balance resulting often in recrystallisation at the product surface (as described above). Migration can be limited by the use of spray-on barriers or the use of fats that are highly nucleating on cooling. In the former case, spray-on barriers can be useful for example in chocolate shells that are to be filled with nut praline. In the latter case, the fats (sometimes called *fractal* fats), when cooled from the melt, create many nuclei that grow to relatively small dimentions, rather than fats that form few nuclei but larger crystals. The effect is to form a very efficient three- dimensional structure that holds liquid fat very efficiently, reducing the rate of migration. These fats must be β' stable.

Process considerations must include cooling the product at an appropriate rate so that resulting crystal forms are stable and not prevalent to transformation. Thus cooling a baked product too rapidly (say from 30C to below 14C) often results in retention of some α crystal. This will move to β' crystal on standing, a condition that can cause temporary surface bloom. Alternatively, packing the product too hot (>25C) and then providing an insulated environment, such as on a pallet, can cause slow crystallisation with large crystal growth and separation of solid and liquid fat phases.

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6. Conclusion

In conclusion, fat bloom is an expensive problem for food manufacturers and significant care has to be exercised to reduce its occurrence. Thermodynamic change will happen, but fat bloom is not inevitable if care is taken over the selection of fats that have to be adjacent in a product. Care must also be taken in process control and this has to include consideration of all aspects from ingredient mixing, through packaging, transport and storage.

We have attempted to describe types of bloom and the way in which they can occur in fat based products. We have discussed the relative complexity involved in trying to limit fat bloom. We believe that it is important to generate such understanding of products because bloom issues are time-related. Current food industry structure can involve products being transported over large distances and to variable ambient climatic conditions. These can include high temperatures and also high humidities. To these times are added the turnover time of the product, which may be quite different for the large and small retailer. Getting the thermodynamic balance right is a challenge for the producer, but the prize is worth the effort in terms of quality and loss.

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