The Role of Fat Crystallization in Bakery Products

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Fats and oils are an important part of the human diet, and there are many fat-rich products in which the role and functionality of fat are critical for achieving good product performance. An obvious example is chocolate. The snap of a chocolate bar and the cooling melt-in-the-mouth sensation that provides an indulgent chocolate experience arise from the specific properties of the composition and the polymorphic character of the form V cocoa butter crystals. Other examples include margarines, low-fat spreads, and mayonnaise.

The functionality of fat crystals and structure are also critical in bakery products. Different products have different requirements of the fat phase and, consequently, require different fat compositions. Fat selection, therefore, is based on the functionality required for a specific product application. For example, in the case of puff pastry a highly saturated fat product is needed. The fat must sheet and then fold and deform with the dough as the pastry is prepared and must not crack or shrink during this process. Consequently, a highly processed product with an appropriate hardness and viscosity is required.

Over the past 10 years or so there has been an increasing recognition of the effects of diet on health. This has driven manufacturers to include healthier, nutritionally enhanced fats and oils in foods. As a result, trans fats have virtually been eliminated, and the amount of saturated fats used in applications has been significantly reduced. Where possible, these fats are replaced with unsaturated oils. Currently, there is also a push to include bioactive, nutritional lipids in foods. For example, sterols, which have been demonstrated to lower blood cholesterol, are being added to many different food products. Manufacturers have also focused on reducing the energy value of foods. Because fats are high in calories (9 kJ/g), one obvious way to reduce the caloric value of a food is to reduce or even completely remove the fat from it.

It is clear that the use of less saturated oils is required to improve the health effects of many foods. In order to develop less saturated oils that provide the necessary functionality in bakery products, oil manufacturers are experimenting with different processing techniques. Interesterification is one such technique. In interesterification the fatty acids in a fat blend are rearranged, and the location of different molecules are optimized to maximize the hardness of a specific blend. Two types of interesterification are used. Chemical interesterification is a fast process, and full randomization of the fatty acid chains quickly ensues. Enzymatic interesterification is a slower, more natural process in which it is possible to control the degree of interesterification of the final product. Other processes include fractionation through partial crystallization to separate hard and soft fats, careful refining, etc.

Although baked goods differ greatly in form and structure, many contain a solid fat component. The properties of this component, including structure and crystallization, are very important in delivering the desired final product characteristics. Different bakery fat systems and the relationship between fat structure and product properties are discussed, as well as how these structures can be altered to develop new products that contain lower amounts of total or solid (saturated and trans) fats.

Fat Structure and Crystallization in Shortening

Structure. The structure of a solid or semisolid material such as a shortening is provided by the individual building blocks of the structural elements within it. In the case of shortening these building blocks are fat crystals. The way in which these blocks are made and connected to together determines the properties of the resulting system.

To successfully build and control the fat structure to deliver optimal functional properties, the underlying crystal structure must be known. The crystal structure depends on the composition of the fat blend, any other ingredients incorporated, and the processing conditions applied. Factors such as temperature, cooling rate, cooling profile, drying rate, and agitation all play a role in development of the crystalline microstructure of fats. Crystal yield, size, number, shape, polymorphic form, and network and whether the system is glassy or amorphous are particularly important structural factors that impact the rheological, mechanical, and physical behavior of the system. These functional properties, in turn, affect the final properties of the product (e.g., sensory characteristics and shelf life) and, ultimately, consumer acceptance.

Understanding the crystallization phenomena of a shortening and how they can be controlled is necessary to achieve the functional attributes required for the final product. The plasticity and solid/liquid ratio (both depend on fat crystallization) are important structural elements of shortening that influence the tenderness, mouthfeel, structural integrity, air incor-
Crytallization Process. To ensure control over the crystallization of fat in shortening, one must understand the nature of the fat and the changes it undergoes during baking. Initially, the fat is melted and culled during shearing. As the temperature drops below the melting point, supersaturation occurs, and crystalline nuclei are formed in the liquid. Crystals grow from these nuclei, and growth continues until equilibrium is reached. However, this may not be the end of the crystallization process. Recrystallization can occur in shortening during storage, which can lead to significant changes in structure. Larger stable crystals usually grow at the expense of smaller ones, which can completely change the structure and functionality of a shortening.

Processing conditions greatly affect the rates of fat nucleation and crystallization. Fast shearing generally leads to the formation of many nuclei, resulting in smaller crystals. Smaller crystals create a stronger, more ductile product. Slow cooling (or higher rates of recrystallization) produces much larger crystals and, consequently, a harder, more brittle product. Therefore, processing conditions can be controlled to produce subtle changes in the properties of a shortening that will determine its functionality.

Fat Crystal Forms. Control of fat crystallization is complicated further by the fact that fats are polymorphic (i.e., they have different crystal forms with different melting points). There are three main polymorphic forms: α, β', and β (in order of increasing stability) (Fig. 1). Over time polymorphic fat crystals transform into more stable polymorphs. When a shortening is manufactured, it is the α form that is nucleated first. However, this is not a stable form and, so, transforms quickly into the β' form. Although this form is often required for its functional properties, it is not a stable form, and recrystallization into the β form may occur. Typically β crystals are larger, and the resultant system is less ductile and functional.

Recrystallization is promoted at higher temperatures or by temperature cycling, which encourages partial melting and slow recrystallization into the more stable form.

It might be assumed that controlling crystallization so the desired polymorphic form is achieved is all that is needed to produce the required functional properties. However, the shape of fat crystals can also have a major impact on performance. Generally β' crystals are shaped like needles, whereas β crystals are shaped like plates. As discussed above, however, crystal size and shape are affected by processing conditions.

To control crystal size and shape, the system can be manipulated through added components. Many molecules, such as emulsifiers, can interfere with the growth of fat crystals and change their shape and size. Addition of very small amounts of certain components (e.g., lecithins, monoglycerides, or diglycerides) can dramatically effect the performance of the resultant product, making it possible to significantly change the properties of a shortening without changing the polymorphic form or melting point of the system. The ability to design and develop new systems with new properties opens up an array of product development opportunities.

Solid Fats. The solid fat content (SFC) is the solid fraction of a fat at a particular temperature. A plastic shortening is a two-phase system consisting of fat crystals surrounded by liquid oil. Although the properties of a system can be manipulated, the SFC provides a basic picture of the properties of a fat, such as spreadability, consistency, and stability and the temperature range over which it is workable. SFC is widely used to describe a fat and to determine whether it is suitable for a particular application, as well as its functionality in food systems.

Use of Shortening in Bakery Products
To evaluate the role and optimization of shortening in a bakery application, the manufacturing process and functionality requirements of the specific product must be considered. Bread provides a good example.

Typically bread contains a small percentage of oil or shortening. Smith and Johansson (8) studied the effects of SFC on bread performance. The volume and weight of loaves baked with oil (without solid fat) or with shortening with different amounts of solid fat are shown in Figure 2. The graph clearly shows that adding any fat to a dough increased the volume of the baked loaf. Loaf volume increased with increasing amounts of solid fat in the shortening, which would make it more desirable.

During dough mixing, oil droplets are mixed into and distributed throughout the dough. Droplets that are near air cells can coat these cells during baking. This provides a stronger interface and enables greater expansion of the air cell, producing a higher rise. When solid fats are added to dough, the fat crystals adhere to the oil droplets, increasing their functionality during baking and making greater rise possible. Consequently, increasing the
amount of solid fat can lead to an increase in bread loaf volume.

Bread staling and shelf life are also concerns. The hardness of loaves baked with oil (without solid fat) or with shortening with increasing amounts of solid fat is shown in Figure 3. The graph clearly shows that loaves baked with solid fat were softer and took longer to harden (stale). Staling is caused by starch recrystallization, and it is thought that solid (saturated) fats are able to slow this process more effectively than liquid (unsaturated) oils. We speculate that the linear molecules in saturated fat are able to complex with the starch and hinder its recrystallization in a way that the kinked fatty acid chains in unsaturated oils cannot.

Identification of the fat system properties desired for a specific application can enable design of functional systems in which the use of solid fats can be reduced. If the structural properties of the solid fats can be ascertained, then they can be replaced with an ingredient that is lower in calories or that may have more health benefits. One example is Coasun, an alternative shortening that is trans fat-free and low in saturated fats, which has been developed by Canadians Alex Marangoni and Steve Bernet (6). In this shortening system, emulsion droplets are used to create a structure that can replace solid fats. Other researchers around the world also are working with different systems that can be used to replace solid fats. Examples include sterol esters (5), ethyl cellulose (4), lecithins (1), emulsion droplets (3), and partial glycerides (2). In all of these cases the aim is to reduce the saturated fat and calorie content of shortening systems.

Continuing research is providing insight into how to optimize use of shortening in bakery products. It is expected that manufacturers will drive innovation that will lead to increasingly functional and healthier systems. Higher quality bakery products are possible, as well as nutritional labels that are more appealing to consumers.

Conclusions

Research has demonstrated that composition and processing conditions can be used to manipulate and optimize the functional properties of shortening. The functional properties of a shortening depend on the blend of oils and fats used in its production. In addition, the way in which the fats in the shortening are crystallized and processing conditions affect the structure and resulting functionality of a system.

Continuing research efforts are increasing our understanding of the functionality of fats, and new systems are being developed in which fats are replaced, at least partially, with other ingredients without dramatically affecting the functionality of the system. These innovations are providing opportunities for manufacturers to create improved shortenings and for bakers to explore alternative fat systems that will deliver enhanced bakery products.

References