Consumers appreciate the importance of butter behavior. Refrigerated butter can be difficult to spread, but, when left on the kitchen counter on a warm day, butter becomes excessively soft and oily.

What consumers may not appreciate about butter is that its behavior, including its texture, depends on the crystallization of an underlying fat crystal network. Butter typically contains at least 80% milkfat and not more than 20% water. It is a multiphase emulsion consisting of aqueous droplets dispersed in a continuous oil phase. The continuous phase contains both crystallized and liquid fat and remnants of the original fat globules that were ruptured during churning. The network of crystalline fat that extends throughout the oil phase provides butter with its structural integrity. Therefore, butter’s functionality and its acceptability to consumers are intimately linked to milkfat crystallization.

Crystallization is the change of state from a liquid to a solid. It involves the formation of tiny crystal nuclei and subsequent crystal growth. Once fat crystals are formed, the crystals, suspended in liquid oil, aggregate into a three-dimensional network because of weak attractive (van der Waals’) forces. The resulting crystal network is responsible for the complex rheological behaviors of both milkfat and butter. Both fats are viscoelastic (i.e., they exhibit both liquid and solid-like characteristics) as well as plastic (i.e., they can withstand a certain amount of force before they yield or begin to flow) over a wide temperature range. When plastic materials begin to flow, shear-thinning, in which a material appears to be less viscous when higher levels of shear are applied, takes place.

The extent to which milkfat crystallizes depends on temperature. Crystallization begins when the environmental temperature is below the melting temperature of the molecules in question. This temperature difference is the driving force for crystallization. In homogeneous substances, like water, crystallization occurs at a specific temperature. In milkfat, however, crystallization occurs over a temperature range because milkfat contains a wide variety of triacylglycerol molecules with melting temperatures between –40 and 40°C. Above 40°C, milkfat is completely liquid and below –40°C milkfat is completely solid. Between these temperatures the fat is partially crystalline. Solid fat content (SFC) refers to the proportion of fat that is solidified. SFC is the biggest determinant of hardness in a fat crystal network. Generally, good spreadability is achieved when a fat possesses between 20 and 40% solid fat (Figure 1). The accompanying graph demonstrates why butter is difficult to spread at refrigeration temperatures. Between 4 and 8°C the SFC of milkfat is around 50%.

SFC is influenced by fatty acid composition. Higher levels of saturates (i.e., a lower iodine value) translate to higher SFC and hence a harder fat. Winter butter, for example, is typically harder than summer butter. This difference is attributable to seasonal variations in cow feed that result in a lower iodine value in winter milkfat. Indeed, the plasticity of milkfat-based spreads can be altered by changing their proportion of unsaturated molecules. This can be accomplished by fractionating, by blending, or by manipulating the milk’s composition through feeding or genetic means. Although SFC is very important, it is not the only determinant of butter consistency. Other properties of the fat crystal network, including crystal size, shape, and arrangement, also influence consistency. For example, smaller crystals tend to be associated with a harder butter.

Two other considerations in milkfat crystallization are polymorphism and mixed crystal formation. Polymorphism refers to the situation in which materials of the same chemical composition possess different packing arrangements of their constituent atoms in the solid state. Whereas several crystal polymorphs have been identified in milkfat, the beta prime (β′) predominates. Nucleation generally occurs in a metastable form called alpha (α), but these crystals quickly transform into the more stable β′. Milkfat is considered to be a β′ fat because the majority of fat remains in this modification even after prolonged storage. The theory of mixed crystal formation has been used to explain some of milkfat’s complex crystallization behavior. Mixed crystals, sometimes called compound crystals, contain more than one molecular species (i.e., more than one type of triacylglycerol). Not surprisingly, mixed crystals are especially common in natural fats, like milkfat, which have varied and complex compositions. Mixed crystal formation results in more solid fat being formed during rapid cooling as compared to during slow or stepwise cooling.

Figure 1. Effect of temperature on solid fat content.
When butter is manufactured, processing conditions, including cooling rate and agitation, are used to control and manipulate milkfat crystallization. Temperature treatments are most commonly used to achieve desirable texture and functionality. For example, the rate at which cream is cooled after pasteurization will ultimately influence butter’s hardness. Cooling rate determines the ratio of solid to liquid fat that will be present when aging begins. During rapid cooling, many small crystals, and therefore a large crystal surface area, are formed. As a result, a lot of liquid fat will adsorb onto the crystal surface, and the amount of liquid fat available to form the continuous oil phase during churning is reduced.

Pasteurized cream is usually ripened at chilling temperatures before being churned. Cream ripening is considered the most economical and successful way of influencing butter consistency. Various temperature pretreatments have been applied industrially for decades, with most involving a cold-warm-cold temperature regime. Probably the best-known commercial example is the Swedish or Alnarp method. The success of ripening is attributed to an increase in the amount of liquid fat available and the melting of some higher-melting fat crystals during the warming process.

Milkfat can be churned into butter using either a traditional batch process or continuous operations. When cream is churned, the mechanical agitation leads to a partial phase inversion and to agglomeration of the partially crystalline fat and fat globule remnants. If the cream is agitated during the early stages of crystallization, secondary nucleation is promoted. Secondary nucleation, in which crystals are shattered into even smaller crystals onto which growth can occur, leads to more discrete fat crystals and ultimately a softer fat at any given SFC. Continuously churned butter, such as that prepared by the Fritz process, is typically harder and less spreadable than batch-churned butter. These textural differences have been attributed to differences in the degree of crystallinity and also to differences in crystal morphology. For example, the fat crystals in batch-produced butters tend to be larger and more irregular than those prepared by the continuous method. Cooling is more rapid, globule destruction is more extensive, and more mechanical agita- tion occurs before crystallization in scraped-surface heat exchangers as compared to batch tanks.

Once butter is churned it undergoes a plasticizing step. The shearing forces that are applied during working serve to expel more oil and fat crystals from the damaged globules and also aid in dispersing water and salt; this reduces the hardness and is critical to achieving a desirable texture. Even after packaging, butter texture is dynamic. Hardening because of continued fat crystallization can go on for months. The gradual increase in SFC and the associated increase in hardness in manufactured butter are referred to as setting. The extent of setting depends on both storage time and temperature. Temperature fluctuations during transport, commercial display, and even in-home storage can have a drastic influence on butter texture.

Consumers expect certain things from their foods. For butter, texture is a key attribute in determining its acceptability. Butter’s properties, including spreadability, hardness, functionality, melting, appearance, as well as taste, are related to an underlying network of partially crystalline milkfat. Understanding this network is critical to appreciating the complexities of butter behavior. It is also the key to tailoring dairy-based spreads and other milkfat-based products with unique physical properties.

Suggested reading

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