Applications of Milk-Fat Fractions in Confectionery Products[1]

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ABSTRACT: Incompatibilities between fats limit the use of modified milk fat in confectionery applications. To further enhance the use of milk-fat fractions in chocolates and compound coatings, a better understanding of mixed crystallization effects between lipids is required. Recent work documents that high-melting fractions incorporated into chocolates drastically reduce bloom formation and cause less softening than anhydrous milk fat. Isosolids diagrams for mixtures of cocoa butter and milk-fat fractions show that softening occurs due to both dilution effects and a slight eutectic formation. Incorporation of milk-fat fractions into palm kernel oil-based coatings shows some differences with results in chocolates. Milk fat and its fractions cause significant bloom formation in these coatings, as compared to the control, and cause significant softening. However, both milk fat and milk-fat fractions are fully compatible with palm kernel oil, based on isosolids diagrams. Softening occurs only because of dilution effects, rather than eutectic formation. Further work is necessary to understand the effects of milk-fat fractions on bloom formation in compound coatings.
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KEY WORDS: Chocolate, confectionery coatings, fat bloom, milk-fat fractions.

Butter or butter oil (anhydrous milk fat) is used in a wide variety of confectionery products. Butter is used to advantage in high-quality caramel, toffee, and cream fillings, while milk fat and butter oil provide advantages in chocolate. Another potential application of butter oil in confections is in compound coatings and imitation chocolates.

Butter is used in confections primarily for the buttery flavor, although some chocolate manufacturers add 2–3% anhydrous milk fat (AMF) to control hardness of dark chocolate (1). Milk fat is also widely known to inhibit fat bloom formation in chocolates (2). Offsetting these advantages is the relatively high cost of milk fat compared to other fats and oils. In addition, the range of melting point and plasticity of milk fat inhibit its use in some confectionery applications. For this reason, fractionation or modification of milk fat has gained increasing popularity in past years.

In particular, fractionation of milk fat can produce a range of products with different physical and chemical characteristics (3–13). Deffense (14) suggested that three main fractions (high, medium, and low melting) exist in milk fat, although fractionation can produce fractions with melting points ranging from <10 to >50°C (15). These fractions provide an interesting range of products for use as ingredients in the confectionery industry.

In this article, an overview of the information needed to optimize and control the use of milk-fat fractions in the confectionery industry is provided. Specific examples of recent research from the author's laboratory will be used to emphasize these points.

FRACTIONATION/MODIFICATION TECHNOLOGY

Milk fat has been modified through a variety of techniques, as summarized by Kaylegian and Lindsay (15). The most common technique, however, is dry or melt fractionation, where molten milk fat is cooled under agitation until a uniform slurry is obtained. Filtration of this slurry, either by vacuum or pressure filtration, results in two fractions. The solids, remaining on the filter, comprise a hard (higher melting point) fraction while the liquid passing through the filter is a softer (lower melting point) fraction.

Chemical and physical properties of the range of fractions produced by this method have been well-documented (15). Softer fractions with lower melting points typically contain lower levels of long-chain saturated fats, while higher-melting hard fractions contain less of the shorter chain and unsaturated fatty acids. These chemical differences result in the different physical properties (melting point, hardness, etc.) between fractions.

An understanding of the complex lipid interactions between milk-fat fractions and other confectionery fats is necessary for optimizing the application of modified milk fats in confectionery products. This starts with a better understanding of the chemical composition of these components. Because the molecular configuration determines crystallization and polymorphic behavior of fats, we need to develop techniques that allow us to easily, quickly, and accurately determine positional arrangement of fatty acids in triglycerides and to relate this chemical structure to physical properties, such as hardness, bloom formation, and polymorphic effects.

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APPLICATIONS

Milk-fat fractions may be used to enhance butter flavor and modify physical properties of confections, as well as to provide bloom resistance in chocolates. Primary application is in chocolate, but there is potential for using milk-fat fractions in caramels and compound coatings, where true butter flavor may be highly desirable. To date, significant research has only been done to evaluate milk-fat fractions and modified milk fats in chocolates. Here, the possibility for using milk-fat fractions in caramels and compound coatings also will be discussed.

Caramel. Little quantitative work has been done to evaluate use of milk-fat fractions in caramels. In the author's lab, preliminary trials have shown that milk-fat fractions can be used to modify physical characteristics of caramels. Differences in physical properties (i.e., cold flow) and caramel color were observed when different fractions were incorporated into a caramel formulation. Softer (low melting point) fractions gave higher degrees of cold flow in stored caramels. Although we need further work to verify and document these effects, the possibility of altering the physical properties of caramels while still maintaining true butter flavor is intriguing.

CHOCOLATE

A substantial amount of work has been done to evaluate modified milk fat and milk-fat fractions in chocolates (16–25). Again, milk-fat fractions can be used to advantage in chocolates for flavor (milk chocolate) and texture (control of hardness) modification. In addition, AMF and milk-fat fractions can be used to prevent or delay fat bloom formation (2,16,21,24,25). In some cases, however, unwanted or extreme softening of the chocolate may occur. Another concern, when adding milk-fat fractions to chocolate, is alteration of crystallization kinetics of cocoa butter during processing (tempering). Typically, lower temperatures are required for tempering chocolates with added milk fat, although the effects of milk-fat fractions on cocoa butter crystallization have not been documented.

For optimal use of milk-fat fractions in chocolates, we need to understand (i) mechanisms and kinetics of bloom formation, (ii) phase behavior for predicting softening effects, and (iii) crystallization kinetics for proper tempering and cooling tunnel operations.

Bloom inhibition. Over the years, the inhibition effect of milk fat (or modified milk fats) on chocolate bloom has been demonstrated (2,16,21,24). Some recent work clearly shows how AMF and milk-fat fractions inhibit bloom formation in dark chocolate made with Ivory Coast cocoa butter (25). In this study, AMF or milk-fat fractions were added at 2% (w/w) of the formulated chocolate, and bloom was evaluated by measuring change in whiteness index with a colorimeter. Temperature of storage was varied between 19 and 29°C on a six-hour basis for a three-week period, with whiteness index measured periodically. Characteristics of the different milk-fat fractions incorporated into chocolates are shown in Table 1.

TABLE 1
Capillary Melting Points

Sample[a]	Clear point (°C)[b]
CB	31.3 ± 0.2
AMF	36.9 ± 0.1
27/32S	49.2 ± 0.1
32S	48.5 ± 0.2
30S	46.7 ± 0.3
28S	44.6 ± 0.2
23S	42.2 ± 0.2
17S	26.2 ± 0.1
17L	15.3 ± 0.2

[a]Cocoa butter (CB), anhydrous milk fat (AMF), and milk-fat fractions; solid (S) fractions obtained at 27°C then 32°C (27/32S), 32°C (32S), 30°C (30S), 28°C (28S), 23°C (23S), 17°C (17S), and liquid (L) fraction obtained at 17°C (17L).
[b]Average of four trials with standard deviation.

Figure 1 shows that AMF and the harder (higher melting point) milk-fat fractions clearly inhibited bloom formation in this chocolate, made with Ivory Coast cocoa butter. Both time for onset of visual bloom and rate of bloom development were inhibited by these fractions. Middle-melting milk-fat fractions inhibited bloom to a lesser extent, compared to hard fractions, but still slowed the rate of bloom compared to the control chocolate (Fig. 2). In contrast, the softest fractions studied showed virtually no inhibition of bloom (Fig. 3). Table 2 shows the effects of these milk-fat fractions on induction time (onset) for nucleation and bloom rate.

Similar, but slightly different, results have been found previously for chocolates made with a different cocoa butter when mixed with milk-fat fractions made by solvent fractionation (24). Evaluation of bloom formation in chocolates made with an equal weight blend of Malaysian and Brazilian cocoa butters showed some interesting differences from the previous study (25). First, chocolates made with this cocoa butter blend bloomed significantly faster than the chocolate made with Ivory Coast cocoa butter. In fact, the temperatures of cycling for accelerated bloom studies were 16.7 to 26.7°C, compared to 19 to 29°C as described above. When the chocolate

TABLE 2
Bloom Formation Parameters in Dark Chocolate[a]

Added fat	Induction time[b]	SD	Bloom rate[c]	SD
Cocoa butter control	3.6	0.6	12.2	1.2
2% AMF	5.7	0.2	4.8	0.4
2% 27/32S	4.9	0.8	1.9	0.9
2% 32S	5.2	0.3	2.6	0.2
2% 30S	4.8	0.6	3.4	0.1
2% 28S	6.2	0.1	3.1	0.3
2% 23S	5.1	0.4	2.0	0.0
2% 17S	3.4	0.5	6.1	0.4
2% 17L	2.9	0.3	6.7	0.1

[a]After 2% replacement of cocoa butter with AMF or milk-fat fractions. Milk-fat fractions described based on temperature of sequential fractionation and solid (S) or liquid (L) fraction (Ref. 25). See Table 1 for abbreviations.
[b]Average of three trials, in days.
[c]Average of three trials, in change in whiteness index/day.

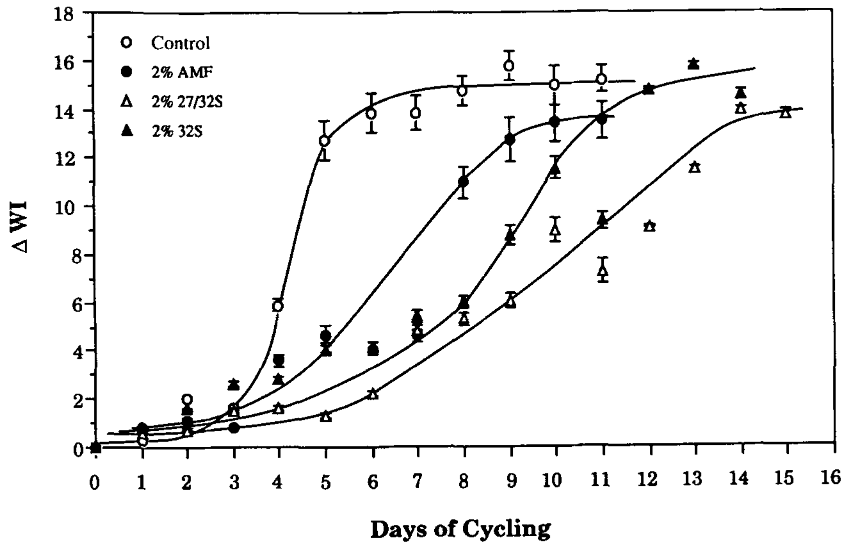

FIG. 1. Accelerated bloom development (change of whiteness index, ΔWI) of dark chocolate [made with Ivory Coast cocoa butter (CB)] containing 2% CB replacement with CB (control), anhydrous milk fat (AMF), and solid (S) milk-fat fractions obtained by melt fractionation at 27°C, then 32°C (27/32S), and 32°C (32S). Bloom development accelerated by cycling between 29 and 19°C at 6-h intervals. Results are averages of three trials, with standard deviations (Ref. 25).

made with Ivory Coast cocoa butter was cycled between 16.7 and 26.7°C, no bloom was observed for at least four weeks, whereas the chocolate made with the Malaysian/Brazilian cocoa butter blend had completely bloomed in three weeks. Hogenbirk (26) also suggested that some cocoa butters are more resistant to bloom than others.

A second difference between the two studies was the shape of the bloom development curve. As seen in Figures 1 to 3, the chocolate made with Ivory Coast cocoa butter exhibited an S-shaped curve for change of whiteness index with time. That is, there was an induction time with no bloom formation followed by a period of more rapid bloom development.

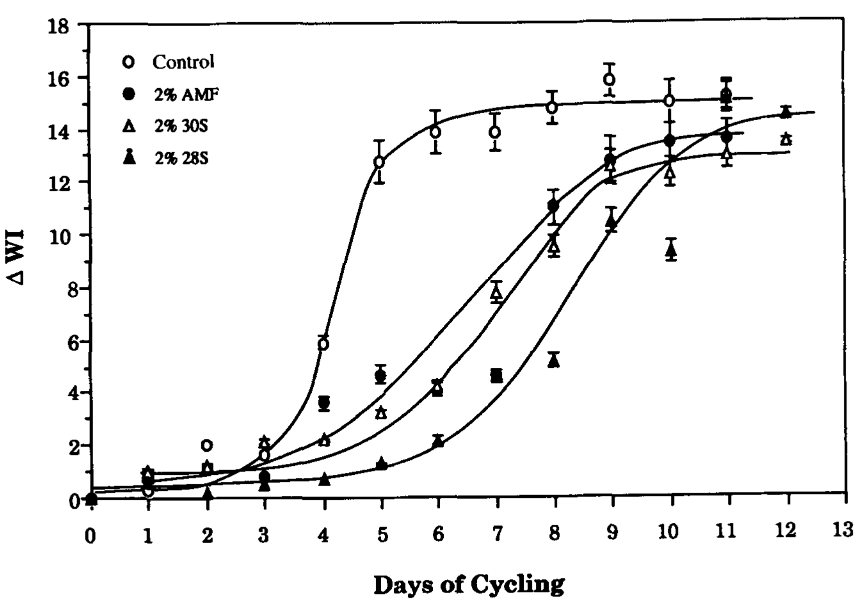

FIG. 2. Accelerated bloom development (ΔWI) of dark chocolate (made with Ivory Coast CB) containing 2% CB replacement with CB (control), AMF, and solid (S) milk-fat fractions obtained by melt fractionation at 30°C (30S) and 28°C (28S). Bloom development accelerated by cycling between 29 and 19°C at 6-h intervals. Results are averages of three trials, with standard deviations (Ref. 25). See Figure 1 for abbreviations.

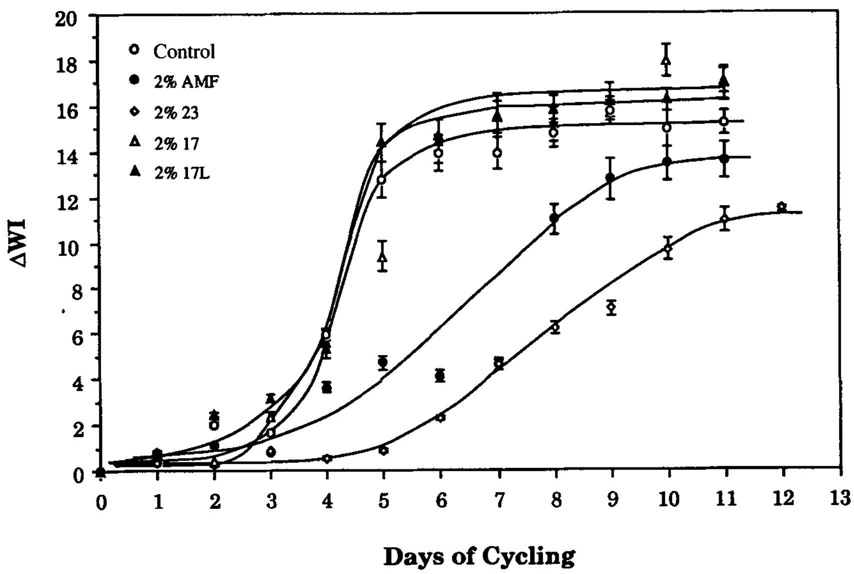

FIG. 3. Accelerated bloom development (ΔWI) of dark chocolate (made with Ivory Coast CB) containing 2% CB replacement with CB (control), AMF, and solid (S) milk-fat fractions obtained by melt fractionation at 23°C (23S) and 17°C (17S), and liquid (L) fraction obtained at 17°C (17L). Bloom development accelerated by cycling between 29 and 19°C at 6-h intervals. Results are averages of three trials, with standard deviations (Ref. 25). See Figure 1 for abbreviations.

Chocolates made with the Malaysian/Brazilian cocoa butter blend resulted in essentially a linear increase in change in whiteness index with time, as seen in Figure 4 (24). The effects of milk-fat fractions on bloom rate in these chocolates (24) are shown in Table 3. As before, the milk-fat fractions with highest melting points inhibited bloom. However, in this case, the milk-fat fractions with low melting point actually promoted bloom, as compared to the control.

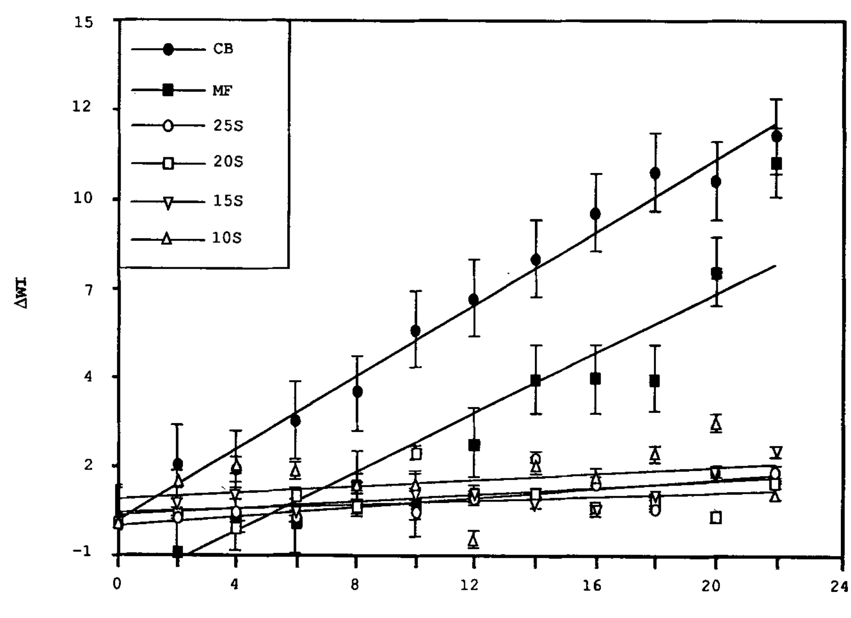

FIG. 4. Accelerated bloom development (ΔWI) of dark chocolate (made with Malaysian/Brazilian CB) containing 2% CB replacement with CB (control), anhydrous milk fat (MF), and solid milk-fat fractions obtained by acetone fractionation at 25°C (25S), 20°C (20S), 15°C (15S), and 10°C (10S). Bloom development accelerated by cycling between 26.7 and 15.7°C at 6-h intervals. Results are averages of three trials, with standard deviations (Ref. 24). See Figure 1 for abbreviations.

TABLE 3
Rate of Bloom Formation (change in whiteness index) in Dark Chocolate[a]

Added fat	Bloom rate[b]	SD
Cocoa butter control	0.53	0.06
2% AMF	0.44	0.06
2% 25S	0.08	0.06
2% 20S	0.03	0.06
2% 15S	0.06	0.06
2% 10S	0.06	0.06
2% 5S	0.79	0.06
2% 0S	1.18	0.06
2% 0L	1.20	0.06

[a]During temperature cycling (26.7 to 15.7°C at 6-h intervals), with 2% replacement of cocoa butter by AMF or milk-fat fractions produced by acetone fractionation. Milk-fat fractions described by temperature of sequential fractionation (Ref. 32). See Table 1 for abbreviations.
[b]Average of two trials, in change in whiteness index/days of cycling.

TABLE 4
Penetration Depth (mm) of Chocolates Made with Milk Fat (AMF) or Milk-Fat Fractions[a]

	Dark chocolate		Milk chocolate	
Added fat	Penetration depth[b]	SD	Penetration depth	SD
Cocoa butter control	1.98	0.03	2.09	0.03
2% AMF	2.03	0.03	2.69	0.05
2% 27/32S	2.04	0.06	2.61	0.03
2% 32S	2.10	0.05	2.56	0.05
2% 30S	2.15	0.04	2.51	0.05
2% 28S	2.10	0.04	2.69	0.05
2% 23S	2.16	0.04	—	—
2% 17S	2.08	0.03	—	—
2% 17L	2.11	0.01	—	—
5% AMF	2.36	0.04	3.11	0.05
5% 27/32S	2.35	0.02	2.86	0.05
5% 32S	2.34	0.02	2.75	0.06
5% 30S	2.39	0.04	2.70	0.04
5% 28S	2.44	0.06	3.05	0.06
10% AMF	2.98	0.05	3.50	0.07
10% 27/32S	2.64	0.06	3.00	0.04
10% 32S	2.63	0.05	3.19	0.05
10% 30S	2.63	0.03	3.18	0.07
10% 28S	2.73	0.07	3.56	0.05

[a]At different replacement levels (2, 5, 10%) for cocoa butter. Milk-fat fractions described based on temperature of sequential fractionation and solid (S) or liquid (L) fraction (Ref. 25). See Table 1 for abbreviations.
[b]Average of four trials.

These differences in bloom inhibition between different milk-fat fractions and cocoa butters must be related to the effects on phase behavior and crystallization kinetics. Differences in chemical composition between fats give rise to differences in compatibility betweens fats in these chocolates. To understand and control these effects, we must understand the complex phase behavior and mixed crystallization of these lipid blends.

Phase behavior and softening effects. Softening of chocolates due to addition of milk fat is widely recognized (1,27) and is attributed to mixed crystallization effects. Typically, milk fat can be added to cocoa butter at up to 30% addition before softening becomes too extreme (1), and product quality is unacceptable. In dark chocolates, however, manufacturers often use a small amount of butter oil to soften the product and control texture (1).

Table 4 shows the softening effect of different milk-fat fractions on dark and milk chocolates. In dark chocolates, penetration depth of a needle probe with 150 g weight increased as chocolates became softer with higher addition levels of AMF or milk-fat fractions. Only at the highest addition level (10% replacement of cocoa butter by milk-fat fraction) was there a significant difference in hardness between chocolates made with AMF or the hardest milk-fat fraction. In milk chocolates, these same general trends applied. However, the mixture of cocoa butter, the original milk fat in the formulation (added in whole milk powder) and added milk-fat fraction resulted in greater softening in these milk chocolates, as compared to the dark chocolates. Again, higher levels of AMF resulted in the greatest softening. Further details of these results can be found elsewhere (25).

To better understand these results, information on phase behavior is required. Phase diagrams for some cocoa butter–AMF or modified AMF mixtures are available (19). These phase diagrams document that addition of milk fat or milk-fat fractions to cocoa butter results in reduced equilibrium temperatures. Additional data are needed for specific mixtures of different cocoa butters and milk-fat fractions. However, phase diagrams for lipid mixtures are difficult to obtain. Another means of demonstrating compatibility of fats is the isosolids diagram, or the related solids content figure. Bigalli (28) has used this method to demonstrate compatibility of various confectionery fats. In the isosolids diagram, lines of constant solid fat content (SFC) are drawn on a plot of temperature vs. composition. Eutectic and dilution effects can be seen from these plots. Eutectic effects, where triglycerides of one fat co-crystallize with the triglycerides of the other fat, are seen as a reduction in the SFC of the mixture below the level of either fat. Dilution effects, on the other hand, result in lines of constant SFC varying linearly with composition.

In Figure 5 (23), the mixture of AMF and the Malaysian/Brazilian cocoa butter blend shows a significant eutectic when the AMF level reaches about 30%. At addition levels above 30%, significant softening occurs. This demonstrates why milk fat is compatible with cocoa butter up to about 30% addition (1,27). Addition of a high-melting fraction (melting point of 49°C) to the same cocoa butter blend resulted in different behavior, as shown in Figure 6. For this high-melting fraction, a significant eutectic occurred at slightly lower levels of addition (20%). Further examples of isosolids diagrams of modified AMF and cocoa butter can be found elsewhere (23).

The advantage of isosolids diagrams is that they are fairly simple to construct, based on SFC measurement for different levels of addition of the two lipids. However, phase diagrams

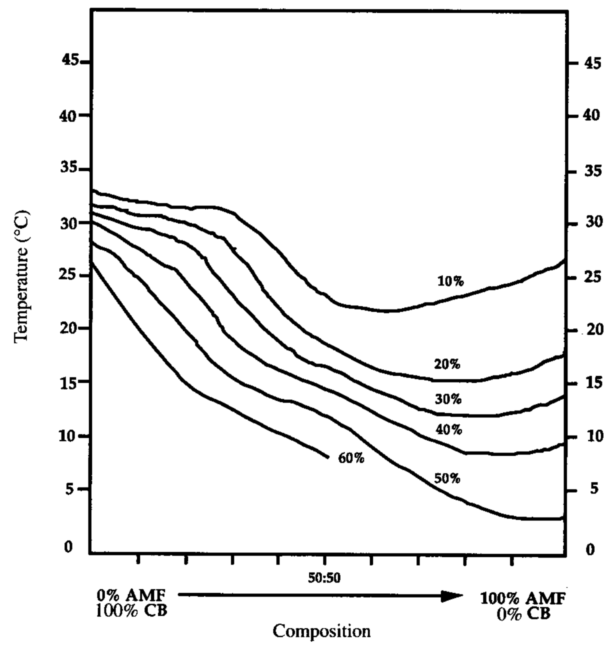

FIG. 5. Isosolid diagram of CB (Malaysian/Brazilian blend) with AMF (Ref. 23). See Figure 1 for abbreviations.

provide a more detailed understanding of the effects of mixed fats on chocolate quality because polymorphic effects are also included. The softening effects shown above (Figs. 5 and 6) are related to modifications of the polymorphic structure of cocoa butter. The addition of higher levels of AMF or milk-fat fractions results in stabilization of β' crystals, rather than the more stable β polymorph found in pure cocoa butter.

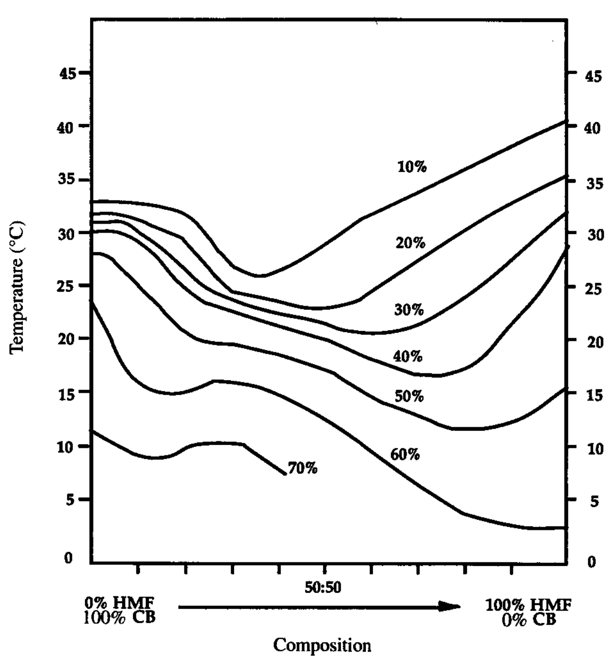

FIG. 6. Isosolid diagram of CB (Malaysian/Brazilian blend) with high-melting milk fat (HMF) fraction (Ref. 23). See Figure 1 for abbreviations.

Thus, phase diagrams can be used to help understand complex interactions between lipids.

However, the thermodynamic equilibria demonstrated in phase diagrams are not sufficient for optimizing use of milk fat or milk-fat fractions in confections. Kinetic effects, controlling the rate of crystal structure formation, are also important, and sometimes may limit the characteristics of food products.

Crystallization kinetics. Rates of crystal formation, growth, and polymorphic transformation of cocoa butter are important for determining processing (tempering) and storage conditions. When milk fat is added to cocoa butter, crystallization rates are reduced (1), and chocolate processing temperatures must be lowered to counteract this decrease in kinetic rate. However, little quantitative data is available that show the rates of cocoa butter crystallization in the presence of milk fat, and virtually no data are available for the effects of milk-fat fractions in the literature. Recent work, with an isothermal differential scanning calorimetry technique, has shown the effects of added milk-fat fractions on cocoa butter crystallization. These results are discussed in a separate article (29).

COMPOUND COATINGS

The imitation chocolate, or compound coating, industry has grown to large proportions as food manufacturers look to make a high-quality, reduced-cost chocolate-type product (1). The best coatings are typically made with palm kernel oil (PKO) because it can be modified (fractionated, interesterified, hydrogenated, etc.) to give melting characteristics similar to cocoa butter-based chocolates. However, PKO is seriously incompatible with other fats, such as cocoa butter and milk fat (1,26). The chocolate or milk flavor of coatings must therefore come from low-fat cocoa powders or milk powders, which generally results in inferior quality. To incorporate milk fat or milk-fat fractions into PKO-based coatings, we must understand the phase behavior and crystallization kinetics of these lipid mixtures as well as the mechanisms of fat-bloom formation.

Bloom formation. Milk fat is known to enhance bloom formation in PKO-based coatings (1) when added even at low levels. However, few quantitative data are available that show rate of bloom formation. A recent study (30) investigated bloom formation in several PKO-based coatings with addition of AMF and milk-fat fractions at different levels. Different milk fats and milk-fat fractions (summer vs. winter AMF, and a range of milk-fat fractions produced by dry fractionation) were added to a sample coating made with a commercial fractionated, hydrogenated PKO. Some typical results for development of bloom during storage at room temperature, as measured by visual rating on a 5 (excellent) to 1 (severely bloomed) scale, are shown in Table 5. The coating made with summer AMF bloomed quite rapidly as compared to the control, while the coating made with winter AMF (a harder fat) was not different from the control. Milk-fat fractions made

TABLE 5
Bloom Development at Ambient Conditions for Coatings Made with Fractionated, Hydrogenated Palm Kernel Oil[a]

	Weeks																						
Coating[b]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
FHPKO-HPO control	4[c]	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	2	2	2	2	1
5% SAMF	4	4	4	4	4	4	4	3	3	3	2	2	1										
5% 17S	4	4	4	4	4	4	4	3	3	3	2	2	1										
5% 21S	4	4	4	4	4	4	3	3	3	3	3	3	2	2	1								
5% 28S	4	4	4	4	4	3	3	3	3	2	2	2	1										
5% 30S	4	4	4	4	4	3	3	3	3	3	2	2	1										
5% 25.5/38S	4	4	4	4	4	3	3	3	3	3	3	2	2	1									
10% SAMF	4	4	4	4	4	4	4	3	3	2	2	1											
10% WAMF	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	2	2	2	1			
10% 17S	4	3	3	3	3	2	2	2	2	1													
10% 21S	4	4	4	4	4	3	3	3	2	2	2	1											
10% 28S	4	4	4	4	3	3	3	3	3	2	2	1											
10% 30S	4	4	4	4	3	3	2	2	2	1													
10% 25.5/38S	4	4	4	4	3	3	3	3	2	2	1												
15% SAMF	4	4	4	4	4	3	3	2	2	1													
15% 17S	4	4	4	4	4	3	3	3	2	2	2	1											
15% 21S	4	4	4	4	4	3	3	3	2	2	1												
15% 28S	4	4	4	3	£	3	£	2	1														
15% 30S	4	4	4	3	3	3	2	2	1														
15% 25.5/38S	4	4	4	3	3	3	3	3	2	2	2	1											

[a]With 2.5% fully hydrogenated palm oil and replacements of anhydrous milk fat and milk-fat fractions.
[b]Control, fully fractionated, hydrogenated palm kernel oil (FHPKO), summer anhydrous milk fat (SAMF), winter anhydrous milk fat (WAMF), and solid (S) milk-fat fractions obtained at 17°C (17S), 21°C (21S), 28°C (28S), 30°C (30S), and 25.5°C and then at 38°C (25.5/38S). HPO is a fully hydrogenated palm oil.
[c]Subjective scores given for bloom: 4 = slightly dull; 3 = dull, traces of bloom; 2 = partly bloomed, appearance not acceptable; 1 = complete light bloom.

by dry fractionation of the summer AMF gave about the same (or even faster) bloom rates as the parent AMF. Similar results were found for other PKO types as well. A general trend was that coatings made with the softer milk-fat fractions (lower melting points) gave slowest bloom formation, while harder fractions typically resulted in the most rapid bloom formation. However, even the softer milk-fat fractions gave bloom rates significantly faster than the control. These results indicate the incompatibility between milk fat and PKO, which results in rapid bloom formation.

The difference in bloom rate between coatings made with summer and winter AMF is interesting, particularly in light of the milk-fat fraction results. Apparently, a fraction of summer AMF was not identified that would give comparable bloom formation as the winter AMF. A study to focus on determining the differences between summer and winter AMF responsible for this effect and to evaluate the potential of milk-fat fractions produced from winter AMF might provide a milk-fat component with the ability to delay bloom formation in coatings.

Phase behavior and softening effects. Addition of AMF to PKO-based coatings also caused significant softening due to the incompatibility of these fats (30). Table 6 shows penetration depth of a needle penetrometer into coatings made with a commercial fractionated, hydrogenated PKO for different levels of summer and winter AMF and for milk-fat fractions produced by dry fractionation of the summer AMF (30). Both

TABLE 6
Penetration Depth (mm) of Compound Coatings[a]

Added fat	Penetration depth[b]	SD
FHPKO control	2.47	0.06
5% AMF	2.70	0.08
5% 25.5/38S	2.49	0.07
5% 30S	2.42	0.08
5% 28S	2.63	0.05
5% 21S	2.53	0.05
5% 17S	2.72	0.04
10% AMF	2.98	0.06
10% 25.5/38S	2.50	0.07
10% 30S	2.57	0.06
10% 28S	2.66	0.07
10% 21S	2.77	0.05
10% 17S	3.12	0.03
15% AMF	3.36	0.07
15% 25.5/38S	2.70	0.04
15% 30S	2.75	0.05
15% 28S	2.77	0.07
15% 21S	2.99	0.06
15% 17S	3.51	0.07

[a]Made with fractionated hydrogenated palm kernel oil (FHPKO) and 2.5% hardened palm oil containing either 5, 10, or 15% PKO replacement with milk fat (AMF) or milk-fat fractions. Milk-fat fractions described based on temperature of sequential fractionation and solid (S) fraction (Ref. 30). See Table 1 for other abbreviations.
[b]Average of five trials.

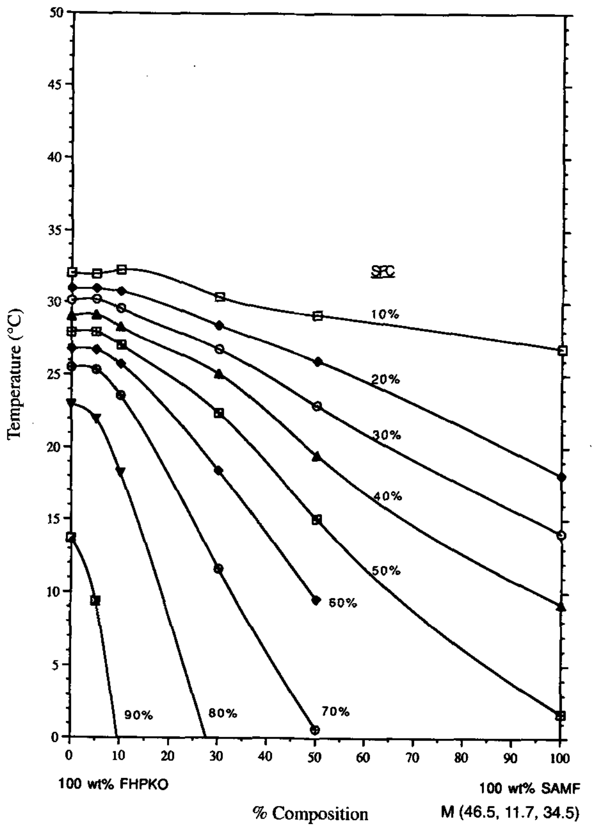

FIG. 7. Isosolid diagram of fractionated, hydrogenated palm kernel oil (FHPKO), hardened with fully hydrogenated palm oil, with AMF (Ref. 29); SFC, solid fat content; M, medium melting (Ref. 31). See Figure 1 for other abbreviations.

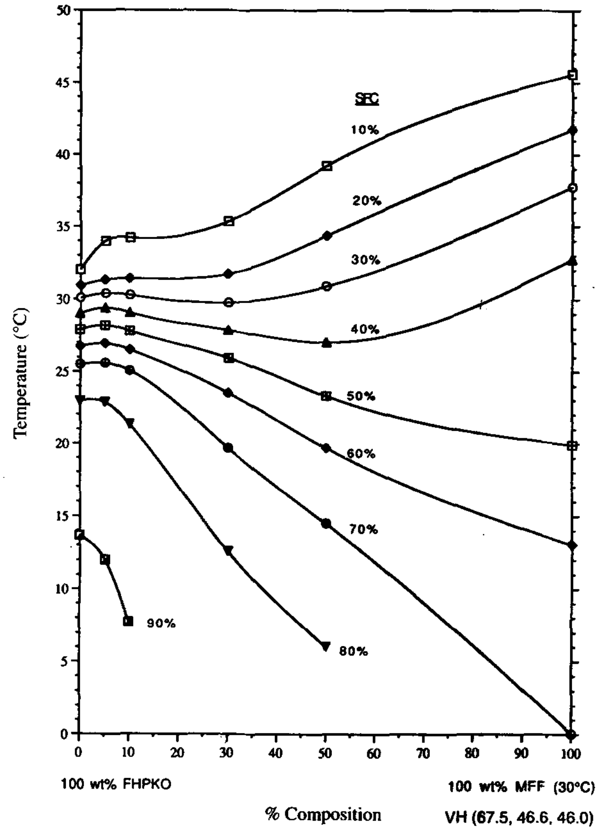

FIG. 8. Isosolid diagram of fractionated, hydrogenated palm kernel oil (FHPKO), hardened with fully hydrogenated palm oil, with hard milk-fat fraction (HMF) (Ref. 31); VH, very high melting.

summer and winter AMF caused significant softening compared to the control coating. The softest milk-fat fractions (melting points of 28.7 and 39.2°C) also caused significant softening, while the harder fractions softened the coatings to a lesser extent. In general, harder fractions caused less softening, and the higher the level of addition, the softer the coatings.

Isosolid diagrams also have been generated for these lipid mixtures (31), which show this softening effect. Mixtures of AMF or milk-fat fractions with this PKO did not result in formation of eutectics, but softening due to dilution effects (Figs. 7 and 8) were apparent. This explains why hardness of coatings made with milk-fat fractions increased with increasing melting point of the milk-fat fraction.

Increased bloom rate correlated directly with increased hardness of milk-fat fractions, as measured by penetration depth and as seen in the isosolids diagram (30). This behavior is the reverse of the typical behavior found in mixtures of cocoa butter and milk-fat fractions, where enhanced bloom was correlated with softer coatings. Undoubtedly, this effect is due to the different mechanisms of bloom formation for cocoa butter and PKO. Further advances in optimizing incorporation of modified milk fat and milk-fat fractions into PKO coatings require a deeper understanding of the effects on both phase behavior and crystallization kinetics.

Crystallization kinetics. Rates of PKO crystal formation and growth must be significantly affected by AMF and milk-fat fractions to produce the results discussed in the preceding section. However, no quantitative data describing these effects are available.

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