Effect of Milk Fat Fractions on Fat Bloom in Dark Chocolate

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Anhydrous milk fat was dissolved in acetone (1:4 wt/vol) and progressively fractionated at 5°C increments from 25 to 0°C. Six solid fractions and one 0°C liquid fraction were obtained. Melting point, melting profile, solid fat content (SFC), fatty acid and triglyceride profiles were measured for each milk fat fraction (MFF). In general, there was a trend of decreased melting point, melting profile, SFC, long-chain saturated fatty acids and large acyl carbon-numbered triglycerides with decreasing fractionation temperature. The MFFs were then added to dark chocolate at 2% (w/w) addition level. In addition, two control chocolates were made, one with 2% (w/w) full milk fat and the other with 2% (w/w) additional cocoa butter. The chocolate samples were evaluated for degree of temper, hardness and fat bloom. Fat bloom was induced with continuous temperature cycling between 26.7 and 15.7°C at 6-h intervals and monitored with a colorimeter. Chocolate hardness results showed softer chocolates with the 10°C solid fraction and low-melting fractions, and harder chocolates with high-melting fractions. Accelerated bloom tests indicated that the 10°C solid MFF and higher-melting fractions (25 to 15°C solid fractions) inhibited bloom, while the lower-melting MFFs (5 and 0°C solid fractions and 0°C liquid fraction) induced bloom compared to the control chocolates.

KEY WORDS: Dark chocolate, fat bloom, fractionation, milk fat fractions.

Fat bloom has been a problem in chocolate manufacturing for many years. Regarded as a major flavor and texture defect, fat bloom is recognized as a grayish white film on the surface of chocolate, causing it to appear dull, old and stale. The surface-dulling appearance of bloom is caused by the scattering of light by clusters of large fat crystals of 5 μm or greater that extend from the surface of the chocolate (1–3).

Fat bloom in chocolate may result due to a variety of reasons. Poor tempering can cause chocolate to bloom rapidly upon solidification and develop a granular crumbly texture in the interior (4). Bloom can also form when fats incompatible with cocoa butter (CB) are added to chocolate (5). In particular, fats that have low solid fat contents (SFCs), such as nut oils, promote bloom formation (3,4,6). However, milk fat (MF) is an exception to the rule. It lowers the melting point of chocolate, but it also inhibits bloom at some levels (7). Another cause of fat bloom is incorrect cooling of tempered chocolates, specifically, rapid cooling (7). Rapid cooling causes small fissures and pores in the chocolate structure during solidification. These small fissures cause internal stress in the chocolate, which, in turn, promotes bloom formation. Warm or fluctuating storage temperatures can also cause bloom to form (8). It is believed that under these conditions, liquid fat readily develops and migrates to the surface as fat bloom. Lastly, enrobed chocolates have a tendency to bloom more easily than molded chocolate bars (7). The condition of the enrobing centers have a great influence on bloom formation. For example, centers with soft fats, high moisture or cool temperature induce bloom formation (7).

It is generally accepted that fat bloom occurs because fat, primarily components of CB, from the chocolate matrix migrates to the surface and crystallizes as fat bloom (9). The specific mechanism by which fat bloom occurs is unknown, although several theories have been proposed. Some researchers (10,11) believe fat bloom is a result of triglyceride phase separation. Partial segregation and recrystallization of the higher- and lower-melting triglycerides result in two separate phases, with the higher-melting phase contributing to bloom. This theory is generally no longer accepted; however, it is an interesting historical look at the evolution of bloom theories. Others (4,12) believe that fat bloom is formed due to polymorphic transformation of CB. They believe that the transformation of unstable crystals to stable crystals results in bloom, in particular, the specific polymorphic transformation from β(V) to β(VI) crystals. Still others (3,13) believe that there are several different possible mechanisms for bloom, depending on conditions. Timms (3) claimed that these mechanisms are triggered by either changes in temperature or composition.

Fat bloom is more a problem with dark chocolate than with milk chocolate because bloom is less visible on milk chocolate, and the high content of MF in milk chocolate helps to inhibit bloom (5,11). The bloom-inhibiting property of MF makes this an attractive ingredient in chocolate. However, the softening effect of MF is an undesirable characteristic, especially in dark chocolate, which is known for its characteristic hard snap. Thus, it is desirable to modify MF so that the bloom-inhibiting properties are retained or improved while decreasing the softening effect.

Modified MF, where the hard fraction is increased or isolated, has been shown to inhibit bloom formation. Modification methods, such as interesterification (14), hydrogenation (15,16) and fractionation (17), have successfully inhibited fat bloom in chocolate. However, it is unknown why MF, and especially the hard fraction of MF, inhibits the formation of fat bloom. For this reason it is desirable to study the bloom-inhibiting properties of MF and its fractions to better understand the fat bloom phenomenon. In this study, bloom formation was quantitated and related to the physical and chemical properties of MF fractions.

EXPERIMENTAL PROCEDURES

Preparation of MF fractions. Summer anhydrous MF (Level Valley Dairy, West Bend, WI) was used for acetone fractionation after residual water and protein were removed. The acetone fractionation method used in this research was executed in the manner as described by Kaylegian and Lindsay (18). Six solid fractions (25S, 20S, 15S, 10S, 5S, 0S) were obtained at 5°C increments from 25 to 0°C, and there was one 0°C liquid fraction (0L).

Intact anhydrous MF, MF fractions and CB were analyzed for melting point, melting profile, SFC, fatty acid and triglyceride compositions. Melting points were analyzed with the AOCS Method Cc 1-25 (19). Melting profiles were determined with a Perkin-Elmer differential

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scanning calorimeter (DSC) 7 (Perkin-Elmer Corporation, Norwalk, CT). The DSC was calibrated with a two-point temperature calibration by using indium and mercury. The lipid samples were heated to 60°C for 3 min to erase past crystalline structure, cooled to −60°C at a rate of 10°C/min and held there for 3 min to induce crystallization, and reheated to 60°C at 10°C/min to record a melting curve.

SFC values of fat samples were analyzed with a Bruker AM400 wide-bore multinuclear spectrometer in conjunction with a Bruker Aspect 3000 off-line data processing station (Bruker Spectrospin, Burlington, Ontario, Canada) at the National Magnetic Resonance (NMR) Facility (Madison, WI). Two different methods were used to measure SFC of the fat samples. A modified AOCS Method Cd 16-81 (20) was used to measure the SFC of MF and milk fat fractions (MFFs), while a modified IUPAC method 2.150 (21) was used to measure the SFC of CB and CB mixtures. CB mixtures were prepared with MFFs to simulate the interaction of CB and MFFs in test chocolates. For the AOCS method, the samples were tempered in the following manner: an initial 30 min hold at 60°C, a transfer to 26°C for 15 min, another transfer to 0°C for 15 min, returning to 26°C for 30 min, and once again to 0°C for an additional 15 min. In the IUPAC method, samples were tempered with a 60°C temperature hold for 30 min, a transfer to 0°C for 90 min, another transfer to 26°C for 40 h, and a return to 0°C for 90 min. After temper, the fat samples and olive oil references were placed inside the NMR, and the liquid signal at 0°C was measured. The fat samples were then placed into a 5°C water bath and held for 30 min for the MF and MFFs, while the CB and CB mixtures were held for 1 h. NMR measurements were taken at the end of this period, and the process was repeated with succeeding 5°C temperature increases until 60°C.

Fatty acid and triglyceride compositions were determined by gas chromatography (Varian Model 3700; Varian Association, Palo Alto, CA) with the procedure of Iverson and Sheppard (22) and Lund (23), respectively.

Preparation of chocolate samples. Dark chocolate samples were prepared by adding 2% (w/w) test fat to dark chocolate base to bring the total fat content of the finished chocolate samples to 31.3% (w/w). The final formulation is as follows: sugar, 51.0% (w/w); chocolate liquor, 37.8% (w/w) (with 53.4% CB) ; CB, 8.7%(w/w); added test fat, 2% (w/w); lecithin, 0.4% (w/w); vanillin, 0.1% (w/w). A 2% (w/w) addition level of MF and MFFs was chosen for this study because this is the minimum amount of MF needed to provide antibloom effects in dark chocolate without a significant softening effect (5). For future reference, the chocolate samples will be identified with the letters "DC" for dark chocolate followed by a designation of the type of fat in the sample. Thus, the nine chocolate samples with the corresponding added fat will be referred to in the following manner: (i) DC-CB, CB; (ii) DC-MF, MF; (iii) DC-25S, 25°C solid fraction; (iv) DC-20S, 20°C solid fraction; (v) DC-15S, 15°C solid fraction; (vi) DC-10S, 10°C solid fraction; (vii) DC-5S, 5°C solid fraction; (viii) DC-0S, 0°C solid fraction; and (ix) DC-0L, 0°C liquid fraction.

The chocolate samples were tempered by using Kleinert's (24) cyclo-thermic tempering method. To determine that all samples were tempered to the same extent, cooling curve profiles were obtained with a tempermeter and Reade's method (25). Similarity in cooling curve profiles between similar chocolate samples is an indication of uniform temper. All the chocolates had similar cooling curve profiles, and thus, effects due to differences in temper were hopefully reduced or eliminated. After temper, chocolate was poured into 12-cavity disc (2″D × 1/4″) molds made of polycarbonate plastic (Tomric Plastics, Buffalo, NY). The molded chocolates were immediately cooled to 14.4–15.6°C with relative humidity of less than 50% and held for 24 h to allow proper solidification.

Chocolate hardness was measured at room temperature with a modified Instron Universal Testing Instrument model 1130 (Instron, Canton, MA). A blunt blade-shaped metal piece (100 mm L × 10.3 mm W) was attached to the Instron crosshead to simulate the human action of breaking chocolate in half. The hardness measurements were normalized and recorded as grams of force per millimeter thickness of chocolate.

Fat bloom. After cooling, the chocolate samples were subjected to an accelerated bloom test with continuous temperature cycling between 26.7 ± 0.7°C and 15.7 ± 0.5°C at 6 h intervals with a relative humidity of 50% or below. Prior to the temperature cycling, one chocolate disc from each mold was measured for initial bloom, and every two days after, another disc from each mold was measured for bloom development.

L*, a* and b* values were obtained with a Hunterlab Tristimulus Colorimeter, model D25A-9 (Hunter Association, Inc., Reston, VA) for fat bloom measurements. To amplify the whiteness of fat bloom from other color components in chocolate, the L*, a* and b* values were converted to the whiteness index (WI) (26) as in Equation 1.

$$WI = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2} \quad [1]$$

To observe the increase of bloom whiteness with time, WI values at zero time were subtracted from WI values at increasing cycling times for each chocolate disc studied (expressed as ΔWI).

RESULTS AND DISCUSSION

MFFs. Approximate yields of the MF fractions were as follows: 2% 25S fraction, 3% 20S fraction, 3% 15S fraction, 2% 10S fraction, 13% 5S fraction, 9% 0S fraction, 23% 0L fraction. No mass balance was performed during the fractionation process.

Table 1 shows the melting points of MF fractions and, as expected, the melting points increased with increasing fractionation temperature.

Figure 1 shows the DSC thermal analyses of test fats pre-tempered initially at 60°C for 3 min, cooled rapidly at 10°C/min down to −60°C for a 3 min hold, and heated to 60°C at 10°C/min to obtain melting profiles. DSC thermal analysis of CB shows two peaks, indicative of an untempered chocolate containing both β' and β polymorphs. Intact MF showed distinctive melting profiles, similar to previous research (18,27–30). The thermal profile showed three major melting components, a low-melting component from 0 to 10°C, a middle-melting component from 10 to 18°C, and a high-melting component from 18 to 36°C. The melting curves of the seven MF fractions followed an expected trend in which the 25S fraction contained mostly the high-melting component, and

TABLE 1

Melting Points of Cocoa Butter (CB), Milk Fat (MF) and MF Fractions

Fraction	Clear point (°C)[a]
CB	32.6 ± 0.2
MF	33.7 ± 0.4
25S[b]	51.5 ± 0.2
20S	50.4 ± 0.1
15S	45.4 ± 0.1
10S	41.0 ± 0.2
5S	30.2 ± 0.3
0S	26.7 ± 0.2
0L	11.3 ± 0.9

[a]Average of three trials, with standard deviation.
[b]Number refers to fractionation temperature; S = solid, L = liquid.

as the fractionation temperature decreased, the thermal peaks shifted to the lower-melting components. The exothermic peaks evident in the 25, 20, 15 and 10°C MFFs indicate the presence of polymorphic transitions.

Figure 2 shows the SFC profiles of each fat sample. All solid fractions had higher SFC than intact MF at low temperatures (below 29°C). The 0L fraction, however, was highly liquid and fully melted at 5°C. The high-melting solid fractions (25S, 20S and 15S) had similar shapes of SFC curves. They were highly solid until 30°C, and then gradually became liquid, being fully melted by 50–55°C. The 5S and 0S fractions had SFC curves similar to CB, although at slightly reduced temperatures. Like CB, the two fractions were solid below 15°C, but above 15°C the SFC quickly decreased as the fractions approached 35°C. However, caution should be exercised in making direct

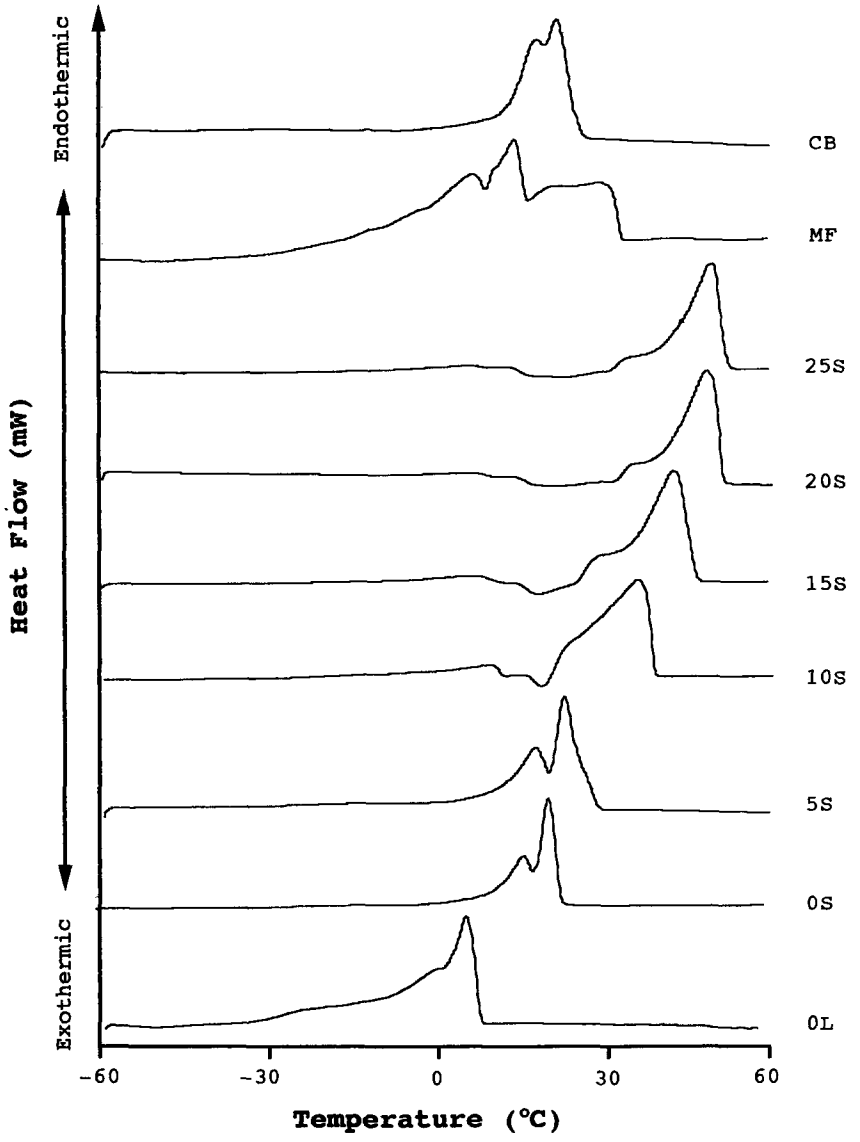

FIG. 1. Differential scanning calorimetry melting profiles of cocoa butter (CB), milk fat (MF) and MF fractions; solid fractions obtained at 25°C (25S), 20°C (20S), 15°C (15S), 10°C (10S), 5°C (5S), 0°C (0S) and a liquid fraction at 0°C (0L).

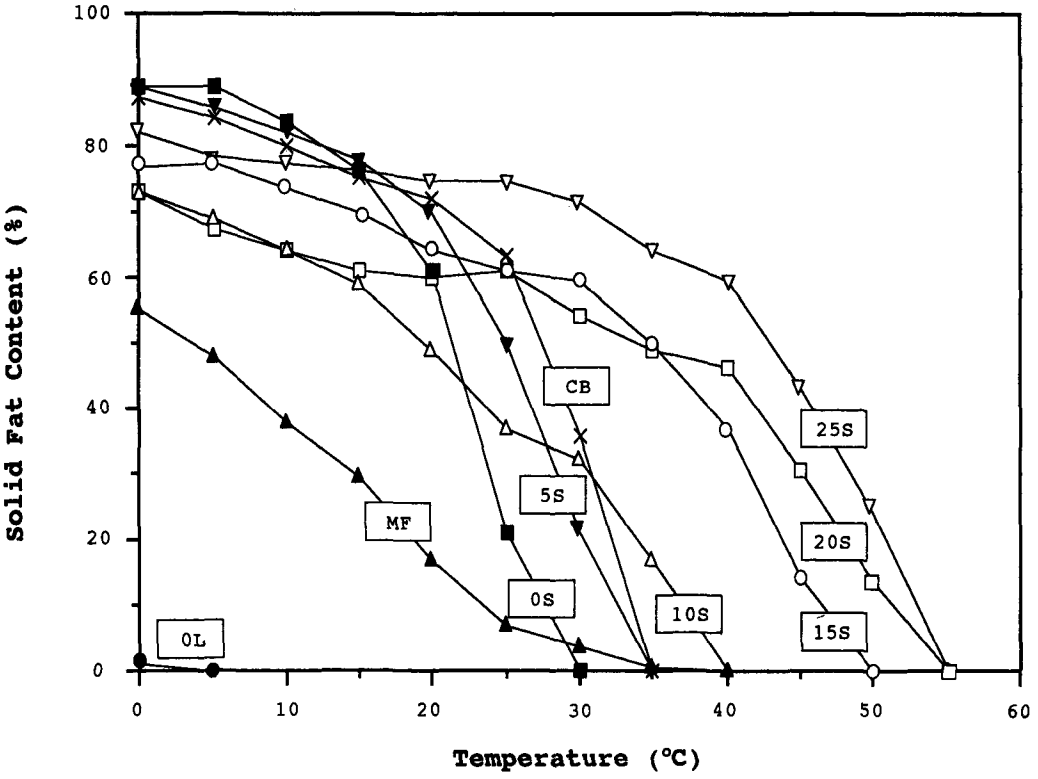

FIG. 2. Solid fat content profiles of cocoa butter (CB), milk fat (MF) and MF fractions; solid fractions obtained at 25°C (25S), 20°C (20S), 15°C (15S), 10°C (10S), 5°C (5S), 0°C (0S) and a liquid fraction at 0°C (0L) (average of three trials, with standard deviation < ± 3% solid fat content).

comparisons between SFC of MFFs and CB because different tempering procedures were used. The 10S MFF exhibited an SFC profile somewhere between those of intact MF and CB. It showed a more gradual melting from 0 to 40°C, similar in shape to intact MF.

SFC profiles of CB and MFF mixtures are shown in Figure 3. The SFC profiles of CB/MFF mixtures behaved similarly to pure CB. Up to 20°C, they were mostly solid, but quickly became liquid as the temperature approached 35°C. As expected, the CB/MF mixture was lower in SFC profile than pure CB, because MF has a softening effect on CB (30,31). The CB mixture with the higher-melting fractions (25S, 20S and 15S) had SFC above that of pure CB, while the CB mixtures with the lower-melting fractions (5S, 0S and 0L) had lower SFC than both pure CB and the CB/MF mixture. The 10S fraction, despite the high melting point (Table 1) and high-melting composition (Fig. 1), decreased the SFC of CB the same as the lower-melting fractions (5S, 0S and 0L). Perhaps the lower SFC of the 10S fraction (Fig. 2) resulted in the reduced SFC of the CB mixture. The SFC curves of the mixtures in Figure 3 cannot be obtained directly from the individual SFC curves of each component (Fig. 2). For example, mixtures of CB and either 10S, 5S, 0S or 0L fractions give essentially identical SFC curves despite the radical differences in SFC of each fraction. In particular, the 0L fraction might be expected to reduce the SFC of CB more substantially than other fractions. These differences illustrate the limitations of using SFC curves to predict characteristics of fat mixtures. Mixed crystallization effects caused by specific triglyceride interactions must also be important and, under certain conditions, are dominant.

Table 2 shows the fatty acid compositions of CB, MF and MFFs. In MFFs, there was a general trend of decreasing levels of LCSFA (long-chain saturated fatty acids) and increasing levels of SCFA (short-chain fatty acids) and LCUFA (long-chain unsaturated fatty acids) with decreasing fractionation temperatures. These results are in agreement with general trends observed for previous studies of acetone-fractionated MF (18,32,33). However, irregularities were noted for 25S and 10S fractions. These fractions were unexpectedly lower in LCSFA and higher in LCUFA than ensuing fractions, possibly due to entrainment of liquid fat during filtration in the fractionation process. The most pronounced difference in fatty acid composition was seen between the solid fractions and the liquid fraction, 0L. The 0L fraction had the highest levels of low-melting components [SCFA, MCFA (medium-chain fatty acids) and LCUFA] and the lowest level of LCSFA.

Table 3 shows acyl carbon number profiles of CB, MF and MFFs. In the MFFs, there was a trend of decreased LCTG (long-chain triglycerides) and increased MCTG (medium-chain triglycerides) with decreasing fractionation temperature. The 25S fraction, however, diverged from this trend. The acyl carbon number profile of the 25S fraction appeared to be somewhere between the 15S and 10S fractions. This may be due to problems of high entrainment of liquid fat during filtration, although the DSC

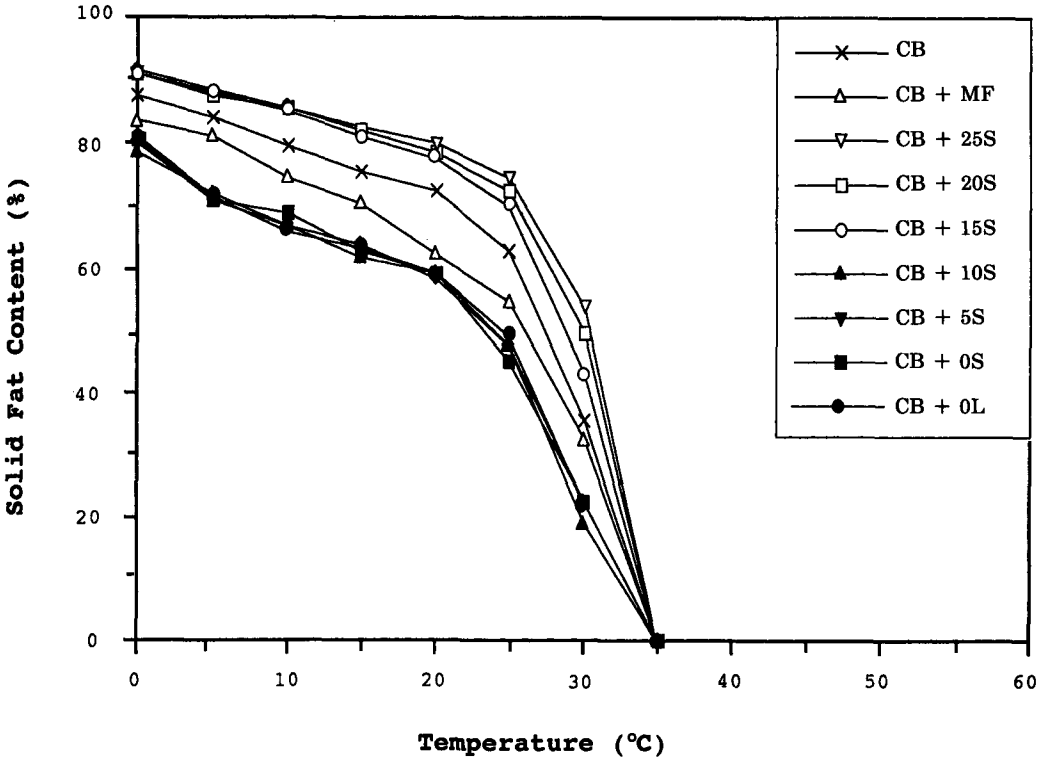

FIG. 3. Solid fat content profiles of cocoa butter (CB) and CB mixtures with 6.4% (w/w) milk fat (MF) or MF fractions; solid fractions obtained at 25°C (25S), 20°C (20S), 15°C (15S), 10°C (10S), 5°C (5S), 0°C (0S) and a liquid fraction at 0°C (0L) (average of three trials, with standard deviation < ± 3% solid fat content).

TABLE 2

Fatty Acid Composition of Cocoa Butter (CB), Milk Fat (MF) and MF Fractions

Fatty acid	Composition (%)[a]								
	CB	MF	25S	20S	15S	10S	5S	0S	0L
4:0	0.0	3.3	0.9	0.8	0.9	1.5	1.9	3.6	4.7
6:0	0.0	1.2	0.3	0.2	0.2	0.4	1.8	1.9	2.7
8:0	0.0	1.3	0.4	0.4	0.5	0.8	1.1	1.1	1.5
10:0	0.0	2.9	0.9	1.2	1.8	2.8	2.8	2.6	3.9
12:0	0.0	3.4	1.9	2.1	3.4	4.2	2.9	2.5	4.2
14:0	0.4	11.6	9.7	12.9	15.0	14.0	9.4	11.3	11.3
14:1	0.0	1.1	0.4	0.3	0.4	0.7	0.7	0.7	1.3
16:0	21.4	32.6	40.1	44.4	42.0	37.3	40.0	42.9	25.5
16:1	0.3	2.1	0.6	0.6	0.8	1.3	1.2	1.2	2.7
18:0	28.9	12.8	25.8	22.7	18.0	15.0	19.0	13.8	7.4
18:1	23.3	23.7	11.1	12.6	15.2	19.8	15.5	15.9	29.9
18:2	24.8	3.0	4.0	1.4	1.4	1.8	2.1	1.9	3.7
18:3	0.2	0.9	2.1	0.2	0.2	0.4	0.4	0.4	1.0
20:0	0.7	0.2	2.0	0.4	0.3	0.2	0.2	0.2	0.3
SCFA	0.0	5.8	1.6	1.4	1.6	2.7	5.8	6.7	8.8
MCFA	0.0	6.3	2.7	3.2	5.2	6.9	5.7	5.1	8.1
LCSFA	51.4	57.2	77.6	80.4	75.3	66.5	68.6	68.2	44.5
LCUFA	48.6	30.8	18.1	15.0	17.9	23.9	19.9	20.1	38.6

[a]Solid fractions obtained at 25°C (25S), 20°C (20S), 15°C (15S), 10°C (10S), 5°C (5S), 0°C (0S) and a liquid fraction at 0°C (0L). Percent composition = (peak area) (weight of internal std.)/(internal std. peak area)(weight of fat). Abbreviations: SCFA = short-chain fatty acids (C4:0–C8:0); MCFA = medium-chain fatty acids (C10:0–C12:0); LCSFA = long-chain saturated fatty acids (C14:0–C20:0); LCUFA = long-chain unsaturated fatty acids (C14:1–C18:3).

TABLE 3

Acyl Carbon Number Profiles of Cocoa Butter (CB), Milk Fat (MF) and MF Fractions

TG[a] carbon number	Composition (%)[b]								
	CB	MF	25S	20S	15S	10S	5S	0S	10L
28	0.0	0.3	0.5	0.0	0.0	0.4	0.1	0.1	0.0
30	0.0	1.0	0.8	0.0	0.0	0.8	0.4	0.3	1.5
32	0.0	2.6	1.4	0.6	0.5	1.6	1.0	0.9	4.1
34	0.0	6.5	2.9	1.6	1.7	4.2	3.6	5.2	9.1
36	0.0	12.8	4.2	2.9	3.6	6.6	11.7	16.9	13.6
38	0.0	15.0	5.2	3.6	4.0	7.3	14.5	16.5	16.4
40	0.0	11.5	4.1	3.1	4.2	6.7	11.1	10.9	13.1
42	0.0	6.7	3.5	3.5	6.5	8.3	9.8	8.0	7.0
44	0.0	7.2	5.5	7.4	13.1	12.6	9.0	6.6	5.8
46	0.0	8.3	11.0	16.5	20.7	13.9	6.9	5.1	5.9
48	0.0	7.0	19.0	23.2	17.5	12.2	8.0	9.0	6.7
50	20.9	9.8	23.4	22.8	16.2	13.2	13.3	12.0	7.1
52	49.1	8.7	15.5	12.3	9.7	9.6	9.0	6.9	7.5
54	30.0	2.6	3.1	2.5	2.3	2.7	1.7	1.5	2.4
SCTG	0.0	3.9	2.7	0.6	0.5	2.8	1.5	1.4	5.6
MCTG	0.0	45.8	16.3	11.3	13.6	24.8	40.9	49.5	52.1
LCTG	100.0	50.3	81.0	88.2	85.9	72.4	57.7	49.1	42.3

[a]Acyl carbon number.
[b]Solid fractions obtained at 25°C (25S), 20°C (20S), 15°C (15S), 10°C (10S), 5°C (5S), 0°C (0S) and a liquid fraction at 0°C (0L). Percent composition = (peak area) (weight of internal std.)/(internal std. peak area)(weight of fat). Abbreviations: TG, triglycerides; SCTG, short-chain TGs (C28–C32), MCTG, medium-chain TGs (C34–C40); LCTG, long-chain TGs (C42–C54).

thermograms do not show significant quantities of lower-melting fractions. A distinct shift in TG composition was apparent between the 10S and 5S fractions. LCTG levels dropped from 72.4% in the 10S fraction to 57.7% in 5S fraction with a concurrent increase in MCTG from 24.8 to 40.9%.

Chocolate samples. The mean force, in g/mm, required to break each chocolate sample in half is shown in Figure 4. Because all the chocolate samples were tempered the same way and had the same cooling curve profile, it is safe to assume that the differences in the hardness values were due to the added fats. An analysis of variance showed that the chocolates made with the higher-melting fractions (25S, 20S and 15S) and CB control were harder at 95% confidence interval than the chocolates made with 10S fraction, lower-melting fractions (5S, 0S and 0L), and with the MF control. Chocolate hardness generally increased with increasing fractionation temperature, although not in a linear fashion. These results are in close agreement with the SFC results of CB/MF and MFF mixtures (Fig. 3). The MF, 10S, 5S, 0S and 0L fractions lowered the SFC profile of CB, just as these fats decreased the hardness of chocolate. In contrast, the 25S, 20S and 15S fractions increased the SFC profile of CB and the hardness of chocolate.

SFC is an important indicator of hardness. Kattenberg (34) studied the effects of three different CBs on hardness in milk chocolate. The CB with the lowest SFC resulted in the softest chocolate. According to Kattenberg, this was because chocolate made with a harder fat contains more fat crystals than with a soft fat. However, the errors associated with hardness tests are generally large, and it is difficult to draw firm conclusions. Nevertheless, the trends in chocolate hardness relative to the SFC profiles of the pure fat systems are worth consideration.

Fat bloom. Accelerated bloom studies were repeated three times, each time with a new batch of freshly tempered chocolate samples. The ΔWI values of these bloom studies were grouped for each treatment and averaged. These values were plotted with days of cycling in Figures 5 and 6 to illustrate trends in bloom development. A best fitting line was obtained for all the treatments based on least squared linear regression (R^2): DC-CB = 0.99, DC-MF = 0.92, DC-25S = 0.78, DC-20S = 0.35, DC-15S = 0.64, DC-10S = 0.38, DC-5S = 0.95, DC-0S = 0.98, DC-0L = 0.96. The low (R^2) values of DC-25S, DC-20S, DC-15S and DC-10S are due to high variabilities between average data points and near zero slopes.

Based on data in Figures 5 and 6, it is arguable that blooming occurs in a linear fashion for all treatments. The control DC-CB showed an almost perfect linear bloom pattern. However, results of other treatments show that linear blooming may be an exception. DC-MF and DC-5S showed an initial period of slow bloom development followed by rapid bloom formation. Segmented regression of these data showed that a break point (i.e., end of lag period and start of rapid bloom development) occurred at the eighteenth day of cycling for DC-MF and at the eleventh day for DC-5S. In contrast, test chocolates containing soft MFFs of 0S and 0L showed rapid initial blooming with an eventual leveling off (Fig. 6). These results suggest that there may be different mechanisms for different fractions. For simplicity, however, the data were treated as linear functions so that the slopes of all the treatments could be obtained and statistically compared.

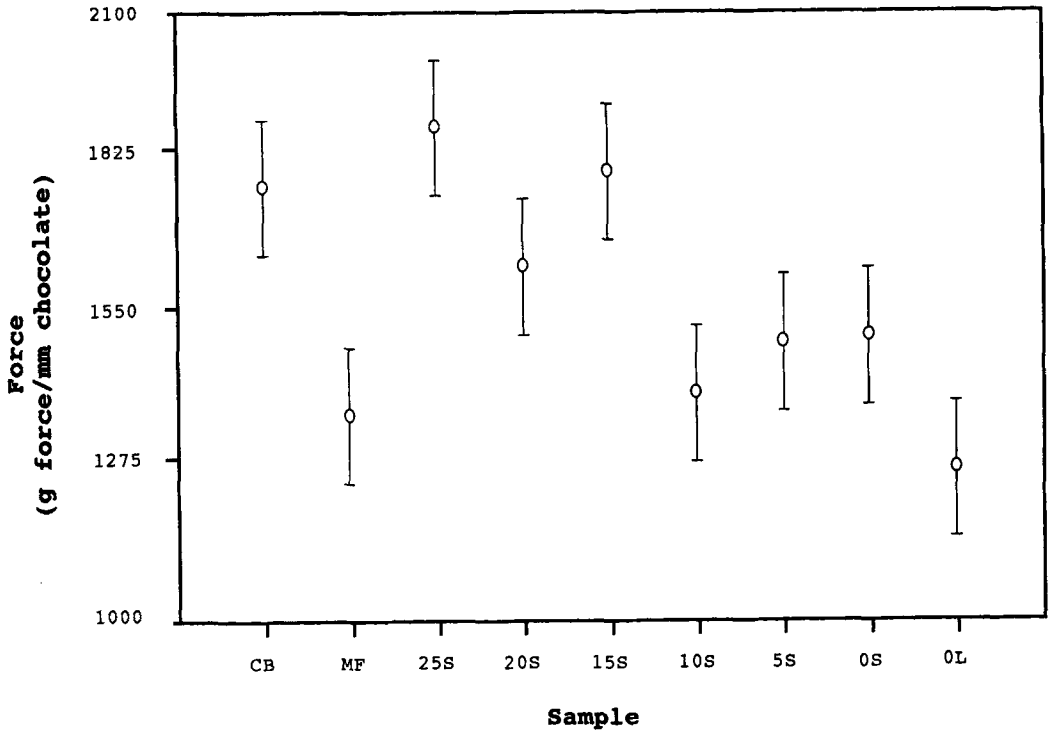

FIG. 4. Instron hardness values for dark chocolate samples containing 2% (w/w) addition of either cocoa butter (CB), milk fat (MF), or MF fractions; solid fractions obtained at 25°C (25S), 20°C (20S), 15°C (15S), 10°C (10S), 5°C (5S), 0°C (0S) and a liquid fraction at 0°C (0L) (average of six trials with standard error of ± 122 g/mm).

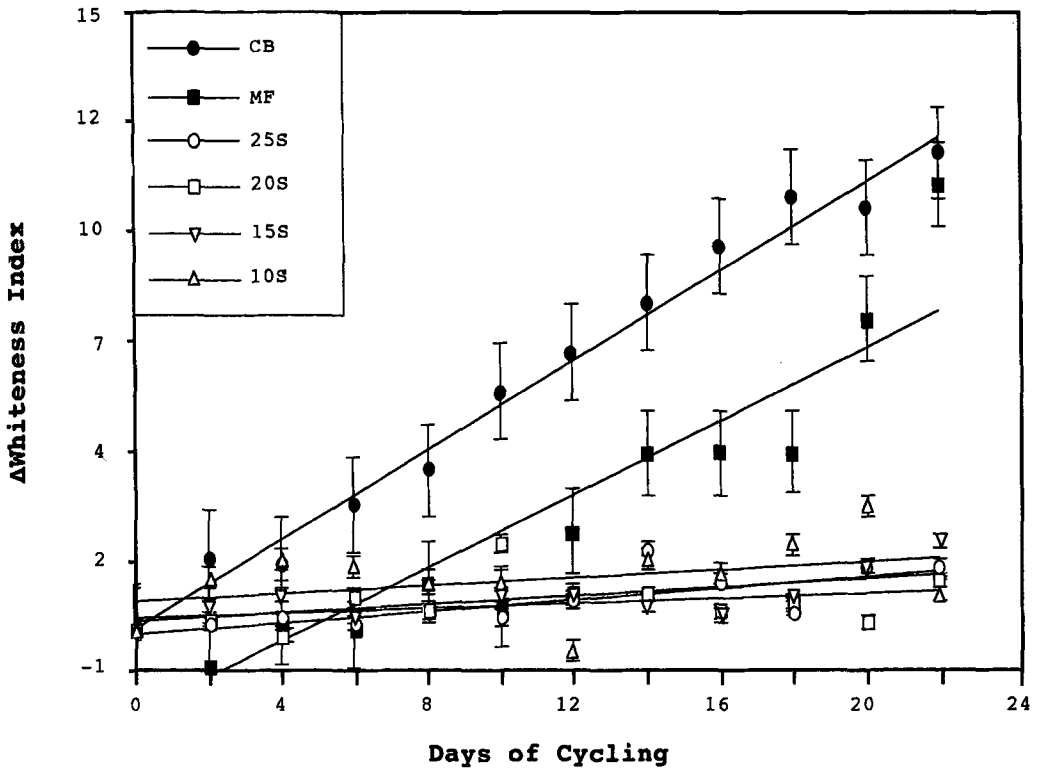

FIG. 5. Bloom development of dark chocolate samples containing 2% (w/w) addition of either cocoa butter (CB), milk fat (MF) or MF fractions; solid fractions obtained at 25°C (25S), 20°C (20S), 15°C (15S), and 10°C (10S) (average of three trials, with standard error bars).

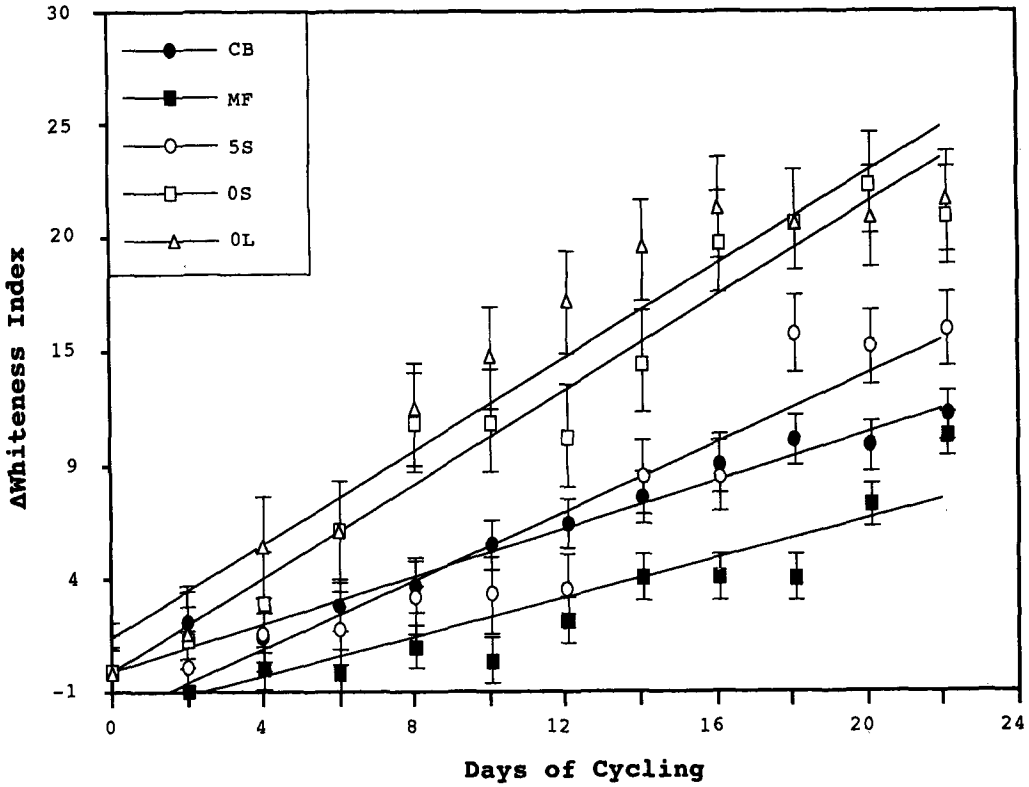

FIG. 6. Bloom development of dark chocolate samples containing 2% (w/w) addition of either cocoa butter (CB), milk fat (MF) or MF fractions; solid fractions obtained at 5°C (5S), 0°C (0S) and a liquid fraction at 0°C (0L) (average of three trials, with standard error bars).

Figure 7 shows a plot of the slopes representative of rates of bloom in ΔWI/days of cycling. Pairwise *t*-tests showed that the control samples, DC-CB and DC-MF, were significantly different at 95% confidence from chocolates containing MFFs. In addition, the chocolates made with high-melting fractions (25S, 20S, 15S, 10S) were significantly different at 95% confidence from samples made with the low-melting fractions (5S, 0S, 0L). A point of distinction appears to be between the chocolate samples made with the 10S and 5S fractions. The chocolates made with 10S, 15S, 20S and 25S fractions had low bloom rates, indicating that these fractions inhibited bloom in chocolate at the 2% (w/w) addition level. Chocolates made with 5S, 0S and 0L fractions had high bloom rates; thus these fractions induced bloom at the 2% (w/w) addition level.

The reason that the low-melting fractions induced bloom could be due to the high amount of liquid fat present at the cycling temperatures, 26.7 and 15.7°C (Fig. 3). The addition of liquid fat to CB has been shown to speed the rate of polymorphic transformation to stable forms (6,35). Liquid fat increases the plasticity of CB, thus leading to increased mobility of TGs and conversion to more stable polymorphs (6). The 10S fraction was an exception. Even though it contained lower SFC than CB at the cycling temperatures (Fig. 3), bloom was inhibited. Other effects, besides SFC, undoubtedly play a role in bloom inhibition, such as degree of saturation/unsaturation, chainlength structure and symmetry of TG composition. The bloom-inhibitive properties of the high-melting MFFs (25S, 20S and 15S) may be due to the more complex crystalline structure and thermal stability provided by high-melting fats (36). According to Schlichter-Aronhime and Garti (9), bloom inhibition is due to the high SFC of high-melting fats, which greatly slow the rate of polymorphic transformation. However, once again, other factors, such as degree of saturation/unsaturation, chainlength structure and symmetry of TG composition may play a role in bloom inhibition. Because little is known about the bloom-inhibitive property of high-melting fractions, further studies in this area are recommended. This work should include efforts to determine the effect of high-melting fractions on the polymorphism of CB.

Anomalous results were obtained for the 10S fraction. Melting point, TG composition and bloom results of 10S fraction showed similar results as high-melting fractions (25S, 20S and 15S), but SFC and chocolate hardness results showed similarity to low-melting fractions (5S, 0S and 0L). Therefore, the 10S fraction may be the key fraction that will lead to better understanding of MF bloom inhibition. A detailed study of interactions between CB and specific TGs prominent in the 10S fraction is warranted. In particular, construction of phase diagrams and observation of polymorphic and compositional changes should be studied.

Differences in chocolate formulation, fat composition, tempering method and temperature cycling conditions prevent direct comparisons with previous bloom studies. However, in general, the results from this study agree with

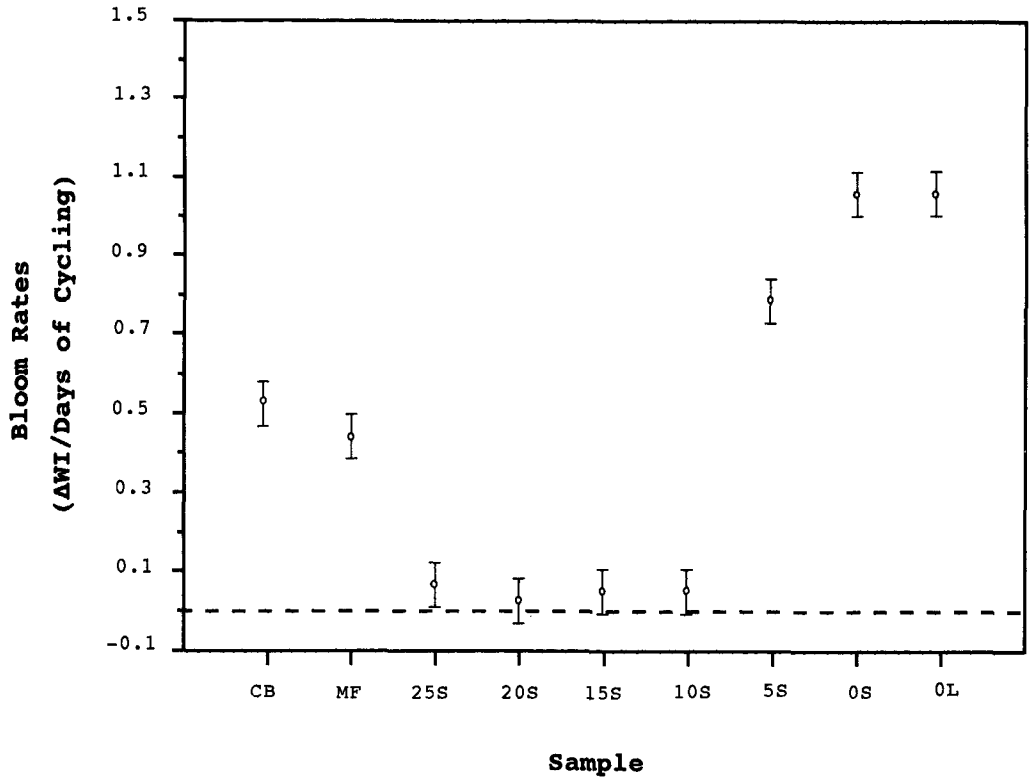

FIG. 7. Bloom rates of dark chocolate samples containing 2% (w/w) addition of either cocoa butter (CB), milk fat (MF) or MF fractions; solid fractions obtained at 25°C (25S), 20°C (20S), 15°C (15S), 10°C (10S), 5°C (5S), 0°C (0S) and a liquid fraction at 0°C (0L) [average of three trials, with standard error ± 0.06 Δwhiteness index (WI)/days of cycling].

previous bloom studies, which show that hard fractions of MF obtained by either interesterification (14), hydrogenation (15,16) or fractionation (17) inhibit bloom. Unlike the previous bloom studies, however, bloom formation was measured instrumentally, and the rate of bloom was quantitated in this study, as opposed to relying on sensory (visual) determination.

In summary, the rate of bloom formation was related to the physical properties and chemical characteristics for a wide range of MFFs.

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