Mixtures of Palm Kernel Oil with Cocoa Butter and Milk Fat in Compound Coatings

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ABSTRACT: Thermal behavior of binary mixtures of palm kernel oil (PKO), cocoa butter (CB), and anhydrous milk fat was used to study mixed-lipid crystallization. This study was related to the physical properties of compound coatings made with these fats. Phase behavior was studied by evaluating changes in melting behavior with composition and time, by creating isosolid diagrams, and by monitoring polymorphic behavior. For binary mixtures, multiple melting peaks and eutectic formation were observed for 30–50% addition levels of CB to PKO, but not for addition of milk fat to PKO. For compound coatings and binary mixtures, made with the same fat composition, hardness of compound coatings increased as solid fat content (SFC) at 25°C of binary mixtures increased. Also, as SFC at 25°C of the binary mixtures increased, induction time for bloom formation and time to fully bloom for compound coatings decreased. Observation of eutectic behavior for binary mixtures indicated softness in a compound coating with the same fat composition, but the converse was not necessarily true.
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KEY WORDS: Compound coatings, fat bloom, hardness, mixed lipids, phase behavior.

It is desirable to enhance flavor and texture of palm kernel oil (PKO)-based compound coatings with addition of fats, such as cocoa butter (CB) or milk fat. The use of milk fat in confections is advantageous because of its abundance and flavor attributes (1). It is also known to inhibit bloom formation in dark chocolate (2). However, use of CB and milk fat in PKO-based coatings is limited. This is due to incompatibilities between these fats, which result in increased bloom formation and/or excess softening of the final product.

Phase behavior of mixed lipid systems has been extensively studied (3–5), although it is not well understood. Eutectic and diluent interactions in fat mixtures have been investigated by using solid fat content (SFC) diagrams by several researchers (5–9). From these diagrams, one can readily determine compatibility of two fats. If two fats are perfectly compatible and exhibit similar melting behavior, the lines of constant SFC lie on straight horizontal lines that connect the melting temperatures of the individual fats. Two fats can also be compatible in phase behavior but have different melting behavior. In this case, lines of constant SFC are straight and connect points for the two pure fats, but decrease in temperature from the harder fat to the softer fat. In this case, diluent softening of the hard fat occurs by addition of the softer fat. For extreme incompatibility between fats, eutectic crystallization effects cause significant depressions in SFC for mixtures of two fats. On the isosolid diagram, this is seen as a compression of the lines of constant SFC and melting temperatures below each of the individual fats. Thus, isosolid diagrams can be used to rapidly distinguish compatibility of two fats.

Timms (9) found that mixtures of milk fat and CB exhibit detrimental eutectic effects at moderate levels of milk fat addition. Eutectic behavior is said to be due to crystal lattice imperfections, increased molecular mobility, changes in polymorphic structure, or changes in crystallization kinetics (5,10), although actual mechanisms are difficult to determine.

Hogenbirk (10) studied mixtures of hydrogenated, fractionated PKO with added milk fat, Malaysian CB, Brazilian CB, and a CB extender. The CB and CB extender caused significant softening of this PKO, owing to eutectic incompatibilities between these fats. Milk fat, on the other hand, caused less softening of the PKO. However, these findings have not been correlated to characteristics of compound coatings, such as hardness and bloom formation, made with these fat mixtures.

Bloom formation in mixed lipids has also been widely studied, and several theories to explain bloom formation have been proposed (5,11–13). Laustsen (13) investigated the effect of CB on fat bloom formation in lauric-based compound coatings. Bloom was caused by a migration of triglycerides containing lauric acid to the surface, rather than migration of the CB. Laustsen (13) also found that bloom occurred faster as the amount of CB increased and suggested that this was due to a eutectic effect caused by the incompatibilities of CB and lauric fats. No work has been published on bloom formation in compound coatings made with added milk fat.

A phenomenon that undoubtedly plays an important role in bloom formation and softening in mixed-fat systems is polymorphic behavior and incompatibility. CB is known to

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form a stable β-polymorph (14), whereas both PKO and milk fat form primarily in the β′-polymorph. At a certain level of CB addition to PKO, stable β crystals will form, causing disruption of the polymorphic network of PKO crystals. On the other hand, β′ crystals of milk fat are likely to be quite compatible with the β′ crystals of PKO.

One objective of this work was to gain more fundamental understanding of the phase behavior of fat mixtures to better understand softening and bloom formation in compound coatings. A second objective was to correlate thermal behavior of simple fat mixtures to hardness and bloom formation in actual compound coatings.

EXPERIMENTAL PROCEDURES

Preparation and analysis of coating samples. Binary mixtures of fats were created by addition of melted milk fat or CB to melted PKO at levels ranging from 0 to 100%, by weight. Additional fats included anhydrous milk fat (AMF) from the summer (SAMF) and winter (WAMF) feeding periods (supplied by Level Valley Dairy, West Bend, WI) and CB from Ivory Coast (ICCB, supplied by Guittard Chocolate Company, Burlingame, CA), Brazil (BCB) and Malaysia (MCB), supplied by Ambrosia Chocolate Co. (Milwaukee, WI). PKO studied included fractionated, hydrogenated PKO (FHPKO), and fractionated PKO (FPKO), which were supplied by Abitec Co. (Columbus, OH) and Loders Croklaan (Lisle, IL), respectively.

Compound coating samples were prepared from a low-fat base provided by the suppliers of each PKO. These coating bases were made with the selected PKO (24–29%), nonfat milk solids (10–20%), sugar (41–52%), defatted cocoa powder (6–8%), vanillin (0.02–0.06%), and lecithin (0.5%). They were refined according to commercial specifications by the supplier. Final coating samples were made by adding AMF or CB, and for the FPKO samples, 2.5% (fat basis) of a fully hydrogenated palm oil (HPO) as a crystallization starter to the low-fat base. The final fat content was always 33.4%. SAMF and ICCB were added to replace 5, 10, or 15% of the PKO in the final coating, while WAMF, and the BCB and MCB were added at 10% level in the FHPKO coating. Similar additions were made to the coating made with FPKO. Full PKO control coatings were prepared in all cases. Melted coatings were poured into warmed 12-cavity disc molds (2″ D × 1/4″) made of polycarbonate plastic (Tomric Plastics, Buffalo, NY). The molds were cooled rapidly at 7°C for 30 min with high air velocity. The coatings were held at 18°C for further testing.

Penetration depth was used as an indication of hardness for compound coatings. A Universal Penetrometer model 73510 (Precision Scientific Petroleum Instruments Company, Bellwood, IL) and the British Standard Method BS 684: Section 1.11: 1976, Method 2 (BSI, 1976) were used to measure the depth of penetration into the sample for fixed time and force. Analysis of variance was used to determine statistically significant differences.

Compound coating samples, stored at room temperature for up to six months, were evaluated visually, on the molded side, once a week for appearance of bloom. The following evaluation code was used in the study: 5 = very glossy; 4 = slightly dull, no gloss; 3 = dull, traces of bloom; 2 = partly bloomed; 1 = fully bloomed. Further details of preparation and analysis of compound coatings can be found in Ransom-Painter (15).

Evaluation of binary fat mixtures. Mixtures of the various PKO with milk fat and CB were evaluated for thermal properties and polymorphic behavior. Each mixture was studied both with and without the addition of 2.5% HPO as a nucleator.

SFC profiles were evaluated with a Bruker Minispec unit, equipped with on-board software for data processing (Bruker, Milton, Ontario, Canada). Nuclear magnetic resonance tubes with a 10-mm diameter were filled with approximately 20–25 mm of fat. The tubes were capped and tempered. Samples that contained CB were tempered according to IUPAC method 2.150 (ex 2.323) (16), which includes holding samples at 60°C for 30 min, 0°C for 90 min, 26°C for 40 h, and 0°C for 90 min. All other samples were tempered according to modified AOCS method Cd 16-81 (17), which specifies a thermal profile of 30 min at 60°C, 15 min at 27°C, 15 min at 0°C, 30 min at 27°C, and 15 min at 0° before reading. SFC was determined at the following temperatures (°C): 0, 5, 10, 15, 20, 25, 30, 32.5, 40, 45, 50, and 60. Measurements were made for each sample on two different days, in triplicate each day, for a total of six readings per sample. The final SFC at each temperature was calculated as an average of these six readings.

Isosolid diagrams were constructed by using an Excel spreadsheet and macro based on an MS-DOS computer program version written by Timms (personal communication). SFC, based on NMR data, for each temperature and for each percentage addition level of a replacement fat to PKO was used to compute temperature values at 10% SFC intervals. Temperature for constant SFC was plotted against composition, with lines created by a three-point interpolation function.

Thermal profiles were generated with a Perkin-Elmer differential scanning calorimeter (DSC) 7 (Norwalk, CT). The DSC was calibrated by a two-point temperature calibration with indium and mercury. Samples were tempered in DSC sample holders with the same methods as for SFC determination. Sample temperature was decreased to −20°C at 100°/min. Samples were then heated from −20 to 60°C at 5°/min, held at 60°C for 3 min and cooled to −20°C at 5°/min to generate melting and cooling curves. Duplicate samples were run for each material.

Polymorphic structure of binary mixtures was investigated with a Nicolet I_2V Polycrystalline X-ray Diffraction System (Nicolet Instrument Corp., Madison, WI) and Siemens Polycrystalline Software Package (Micro-VAX release 2.41, June 1989). The mixtures were melted at 60°C and placed in each x-ray sample disk (Siemens Industrial Automation, Inc., Madison, WI). The samples containing CB were tempered according to IUPAC long method 2.150 (ex 2.323) (16), and those samples not containing CB were tempered according to a modified version of the AOCS Method CD 16-81 (17). After tempering, the surface of each sample was smoothed, and the samples were stored at 13°C throughout 18 wk of storage. Samples were analyzed at 2θ angles of 5° to 35°, and d-spacings were calculated by the accompanying software. Relative intensities of the detected peaks were used to determine polymorphic structure (18).

Gas chromatographic analysis of fatty acid composition of all fats was accomplished by conversion to butyl esters by a modified method of Iverson and Sheppard (19) (model 3400; Varian Associates, Palo Alto, CA). Triacylglycerol profiles were determined by gas chromatography (Varian DS 651) with a modified method of Lund (20).

Clear points were determined by a capillary technique, AOCS Method Cc 1-25 (17). Further details of preparation and analysis of binary fat samples can be found in Williams (21).

RESULTS AND DISCUSSION

Analysis of component fats. Table 1 shows the fatty acid profiles for CB, milk fats, PKO, and the hardened palm oil used in this study. CB were made up of seven fatty acids, of which about 95% was $C_{16:0}$, $C_{18:0}$, and $C_{18:1}$. The fatty acid profiles for the milk fats were more diverse, with fatty acids ranging from $C_{4:0}$ to $C_{18:3}$. A distinct difference was found between SAMF and WAMF, in that SAMF contained more than twice as much short-chain ($C_{4:0}$–$C_{8:0}$) and medium-chain ($C_{10:0}$, $C_{12:0}$) fatty acids, while WAMF had more long-chain saturated ($C_{16:0}$, $C_{18:0}$) fatty acids. Modified PKO contained 40–50% lauric acid ($C_{12:0}$). The most distinct difference between the two PKO was the amount of $C_{18:0}$, which increased for FHPKO due to hydrogenation. HPO, a fully hydrogenated palm oil, consisted of only saturated fatty acids, as expected, and was 98% $C_{16:0}$ and $C_{18:0}$. In considering modification by fractionation and hydrogenation, the composition of PKO and HPO agreed with values reported in the literature (22,23).

Table 2 shows the triacylglycerol profiles for CB, milk fats, PKO, and the hardened palm oil used in this study. The CB were composed of three high molecular weight triacylglycerols, C_{50}, C_{52}, and C_{54}. SAMF was higher in C_{26}–C_{38}, while WAMF was higher in C_{44}–C_{54}. PKO was concentrated in middle molecular weight triacylglycerols (C_{34}–C_{40}). HPO contained 91% high molecular weight triacylglycerols (C_{48}–C_{54}), which corresponded with the large concentration of palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids.

The melting curves of the three CB were similar and exhibited one main melting peak. The thermal profiles for SAMF and WAMF revealed the presence of three distinct melting regions, similar to those found in previous research (24,25). The three major peaks are due to three major groups of glycerides melting independently, and their relative size and position vary with thermal history and triacylglycerol composition (25).

Finally, Table 3 shows the melting (clear) points of the fat samples in this study. Note that the different PKO were chosen to have similar melting points, while the CB and AMF were selected to provide a range of melting points for that fat type.

Analysis of binary fat mixtures. Melting behavior for addition of CB to PKO showed the incompatibility of these fats. The isosolid diagram for the mixture of ICCB and FHPKO (Fig. 1) shows this eutectic behavior, especially in the 30–50% CB addition range. Eutectic behavior, as referred to by Timms (1984), is observed as a constant SFC line, which is not a linear interpolation between pure fats at that SFC. In Figure 1, the decrease in SFC at any temperature in the range of 30–60% addition of ICCB to FHPKO clearly shows the eutectic incompatibility of these two fats. Addition of BCB and MCB to FHPKO, as well as addition of all three CB to FPKO,

TABLE 1
Fatty Acid Profile of Cocoa Butters, Milk Fats, Palm Kernel Oils, and Palm Oil

Fatty acid	Weight %[a]							
	ICCB	MCB	BCB	WAMF	SAMF	FHPKO	FPKO	HPO
$C_{4:0}$	—	—	—	2.7	5.1	—	—	—
$C_{6:0}$	—	—	—	0.7	2.8	—	—	—
$C_{8:0}$	—	—	—	0.4	1.6	1.0	1.0	—
$C_{10:0}$	—	—	—	1.4	3.2	1.9	1.8	—
$C_{12:0}$	—	—	—	2.4	3.4	49.9	47.7	0.2
$C_{14:0}$	0.2	0.1	0.1	10.4	11.2	22.9	22.6	0.9
$C_{14:1}$	—	—	—	0.4	0.3	—	—	—
$C_{16:0}$	25.7	25.7	24.4	34.7	29.4	9.9	10.1	42.5
$C_{16:1}$	0.2	0.2	0.3	1.5	1.4	—	—	—
$C_{18:0}$	39.6	36.6	32.8	16.4	12.6	9.1	3.7	55.9
$C_{18:1}$	30.6	33.2	37.3	24.7	25.3	3.7	8.9	—
$C_{18:2}$	3.0	2.7	3.9	3.5	3.2	1.5	3.9	—
$C_{18:3}$	—	0.2	0.2	0.7	0.6	—	—	—
$C_{20:0}$	0.6	1.2	1.0	—	—	0.2	0.2	0.6

[a] Ivory Coast cocoa butter (ICCB), Malaysian cocoa butter (MCB), Brazilian cocoa butter (BCB), winter anhydrous milk fat (WAMF), summer anydrous milk fat (SAMF), fractionated hydrogenated palm kernel oil (FHPKO), fractionated palm kernel oil (FPKO), and fully hydrogenated palm oil (HPO).

TABLE 2
Acyl Carbon Number Profile of Cocoa Butters, Milk Fats, Palm Kernel Oils, and Palm Oil

Fatty acid	Composition %[a]							
	ICCB	MCB	BCB	WAMF	SAMF	FHPKO	FPKO	HPO
C_{26}	—	—	—	0.3	1.2	1.7	1.6	—
C_{28}	—	—	—	0.5	1.6	2.3	2.0	—
C_{30}	—	—	—	1.1	1.9	1.9	1.8	—
C_{32}	—	—	—	2.1	3.1	4.8	4.7	—
C_{34}	—	—	—	5.6	6.5	7.5	7.3	1.0
C_{36}	—	—	—	10.8	11.7	26.9	25.8	0.5
C_{38}	—	—	—	13.4	13.8	22.4	22.1	3.1
C_{40}	—	—	—	10.7	10.6	12.7	13.0	1.8
C_{42}	—	—	—	6.6	6.6	8.0	8.4	—
C_{44}	—	—	—	6.2	5.8	4.3	4.6	—
C_{46}	—	—	—	6.7	6.4	2.5	2.9	2.8
C_{48}	—	—	—	8.7	7.8	2.2	2.4	11.0
C_{50}	18.0	18.4	17.5	11.1	9.7	1.2	1.0	37.3
C_{52}	46.6	46.7	46.4	10.7	8.6	1.0	1.0	32.1
C_{54}	35.4	34.9	36.0	5.6	4.9	0.8	1.3	10.5

[a]See Table 1 for abbreviations.

showed similar eutectic behavior (data not shown). DSC melting profiles for mixtures of ICCB and FHPKO (Fig. 2) showed simple, single-peak behavior for the pure fats but complex melting behavior between 30 and 50% addition levels. This complex melting behavior occurred in the region of eutectic formation seen in the isosolid diagram (Fig. 1). Addition of BCB and MCB to FHPKO, and all three CB to FPKO, resulted in similar behavior in the melting profiles. The presence of 2.5% HPO in these mixtures had no significant effect on melting behavior as shown in isosolids diagrams.

In contrast, mixtures of SAMF with FHPKO (Fig. 3) showed no evidence of eutectic behavior. Lines of constant SFC were linear, and only a dilution effect was observed (5). In this case, the softening effect of SAMF on FHPKO was directly related to the amount of SAMF present in the mixture. Addition of WAMF to FHPKO, and both milk fats to FPKO, produced similar results (data not shown). DSC melting profiles for addition of SAMF to FHPKO (Fig. 4) exhibited a gradual transformation from that of pure FHPKO to pure SAMF. Complex melting in the 30–50% addition level range did not occur, as observed for CB–PKO mixtures. Addition of WAMF to FHPKO, and both milk fats to FPKO, produced similar results (data not shown). The presence of 2.5% HPO in these mixtures had

TABLE 3
Melting Points of Cocoa Butters, Milk Fats, Palm Kernel Oils, and Palm Oil

Sample[a]	Clear point (°C)[b]
BCB	27.8 ± 0.1
ICCB	31.1 ± 0.1
MCB	32.8 ± 0.1
SAMF	34.5 ± 0.1
WAMF	36.8 ± 0.1
FHPKO	31.8 ± 0.1
FPKO	31.7 ± 0.1
HPO	58.8 ± 0.1

[a]See Table 1 for abbreviations.
[b]Average of three trials ± standard deviation.

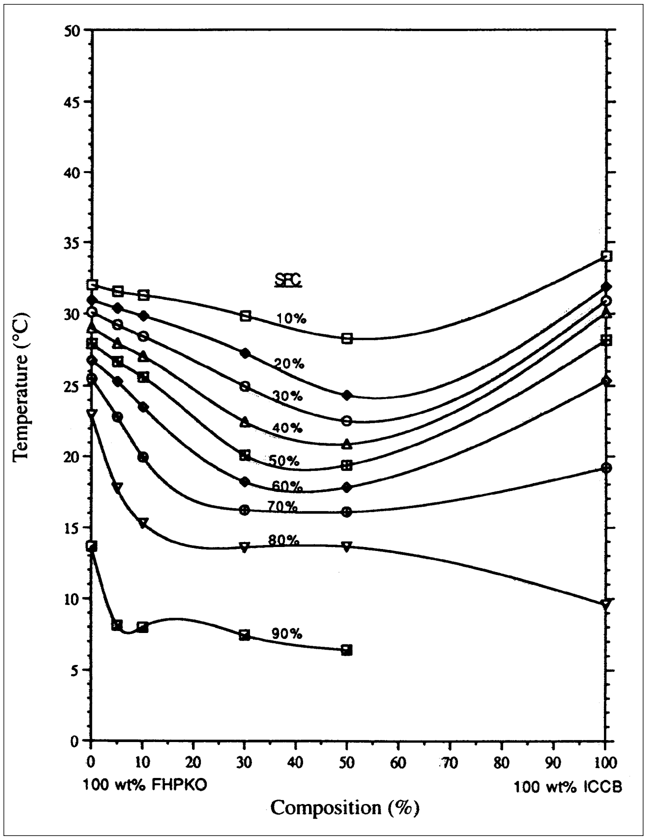

FIG. 1. Isosolid diagram showing solid fat content (SFC) for mixtures of Ivory Coast cocoa butter (ICCB) and fractionated hydrogenated palm kernel oil (FHPKO).

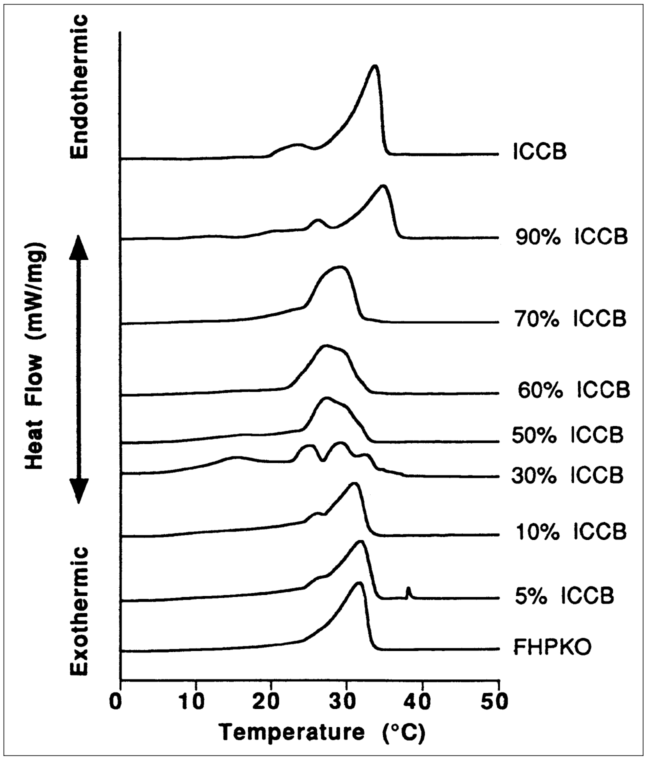

FIG. 2. Melting curves (differential scanning calorimeter; 5°C/min) of mixtures of ICCB and FHPKO. See Figure 1 for abbreviations.

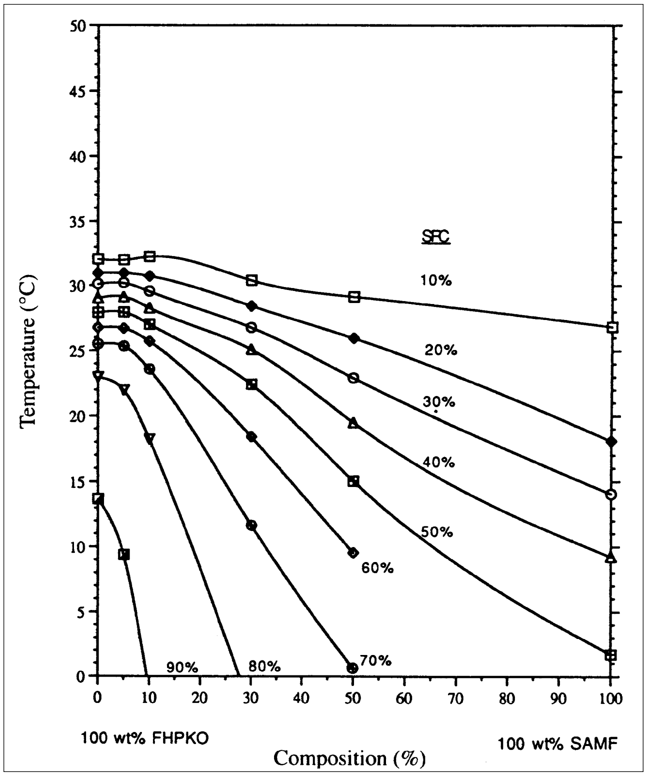

FIG. 3. Isosolid diagrams showing SFC for mixtures of summer anhydrous milk fat (SAMF) and FHPKO. See Figure 1 for abbreviations.

no significant effect on melting behavior as shown in DSC melting curves.

Phase diagrams show regions of liquid, solid and liquid, and solid behavior as a function of composition, but do not demonstrate the complexities of melting of complex fat mixtures. Also, phase diagrams typically are generated under equilibrium conditions, which are not often attained in food systems. To evaluate the approach of the binary fat samples to an equilibrium condition, DSC melting curves were determined during 18 wk of storage at 13°C. For each of the component fats (PKO, AMF, and CB), there were no significant changes in melting behavior, as seen in DSC melting profiles, during this storage period. However, Figure 5 demonstrates the change in melting behavior for a 50:50 (w/w) mixture of FHPKO and ICCB during 18 wk of storage at 13°C. In this case, the three distinct peaks observed after 6 wk of storage gradually converted into a single broad peak after 12 to 18 wk of storage. However, such changes were observed over shorter times for nonequal mixtures of fats. Thermal profiles in this study were measured after at least 11 wk of storage, after which no changes were generally observable.

The polymorphic structure of fat mixtures of ICCB, SAMF, and WAMF with FHPKO and FPKO was determined during 18 wk of storage. α, β′, and β polymorphs were identified according to the nomenclature of Larsson (18). Mixtures containing milk fat and PKO contained only β′ crystals at all times. Mixtures containing less than 40% (w/w) addi-

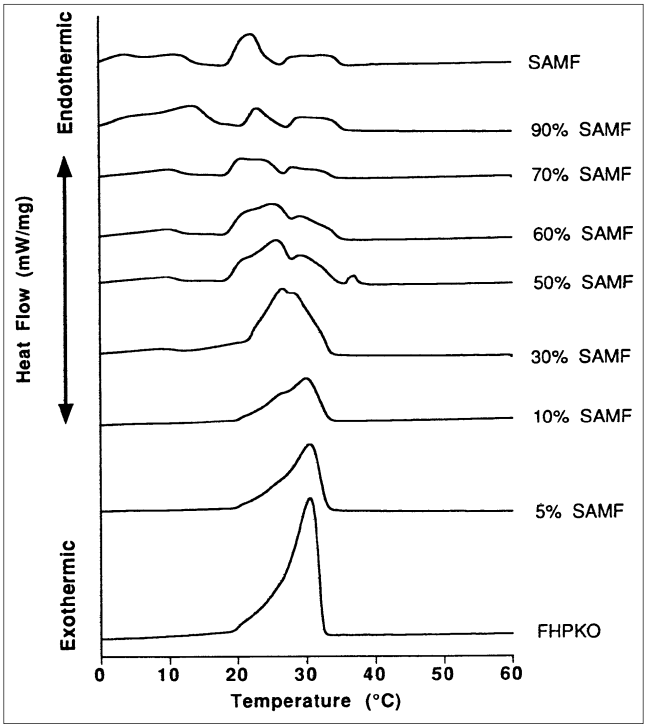

FIG. 4. Melting curves (differential scanning calorimeter; 5°C/min) of mixtures of SAMF and FHPKO. See Figures 1 and 3 for abbreviations.

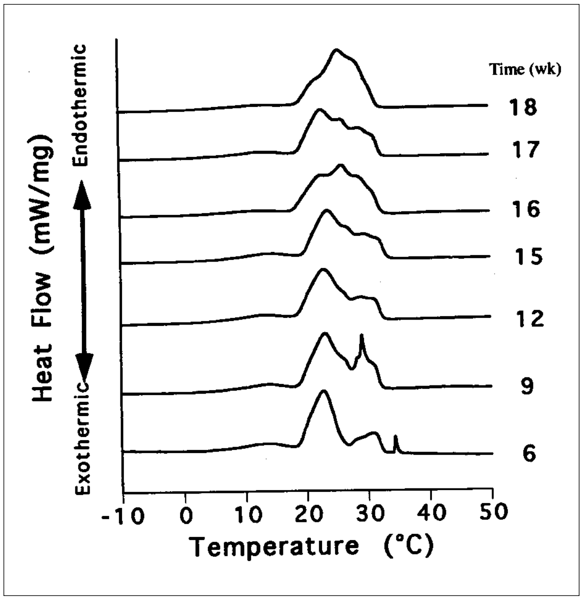

FIG. 5. Change in melting behavior (differential scanning calorimeter; 5°C/min) of 50:50 (w/w) mixture of ICCB and FHPKO during storage at 13°C for 18 wk. See Figure 1 for abbreviations.

tion of ICCB to FHPKO also contained only β′ crystals during 18 wk of storage (Fig. 6). For 40% (w/w) addition of ICCB to FHPKO, the appearance of β crystals was first seen after 18 wk. For a mixture containing 60% (w/w) ICCB, a mixture of β′ and β crystals was observed after 5 wk, while only β crystals were observed in a pure, tempered ICCB sample. Apparently, CB gradually transformed from the β′ to the β polymorph over long periods of storage in mixtures with PKO, and the rate of this conversion depended on the level of CB.

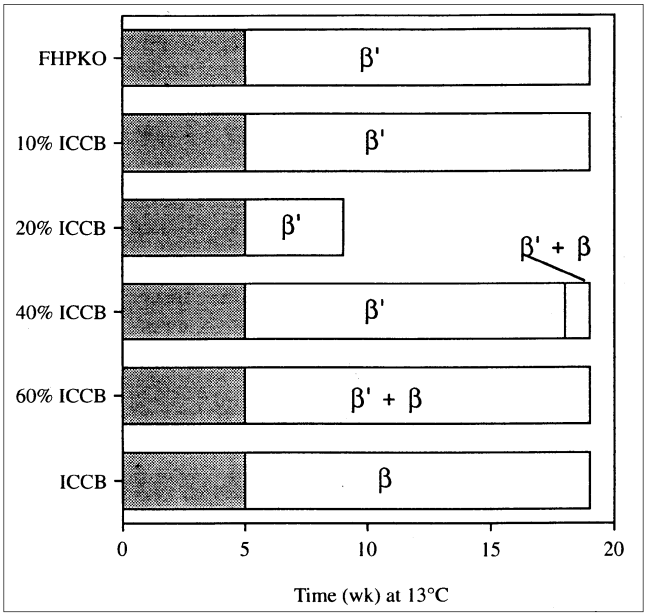

FIG. 6. Change in polymorphic structure of mixtures of ICCB and FHPKO during storage at 13°C for 18 wk. See Figure 1 for abbreviations.

Analysis of compound coatings. Coatings made with FPKO were substantially softer than those made with FHPKO, despite their common melting point. This was due to the difference in SFC curves, where FPKO typically had lower SFC for a given temperature than the FHPKO. Figures 7 and 8 show the penetration depths of coatings made with FHPKO and FPKO (both with 2.5% HPO), respectively. No differences were found in hardness of coatings made with FHPKO upon addition of the three CB at a 10% addition level (Fig. 7). However, for coatings made with FPKO, addition of the CB with highest melting point (MCB) at 10% addition level resulted in a harder coating compared to the other CB. Coatings made with SAMF were as hard as those made with WAMF and were not different from those made with CB. Interestingly, AMF typically gave slightly harder coatings than those made with equivalent levels of CB. Also, there was generally a linear increase in penetration depth with increasing addition level of each of the fats. The addition of a palm oil nucleator (2.5%) did not affect the hardness of compound coatings (data not shown).

Fat bloom was evaluated at ambient conditions over a 10-mon storage period. The nonmolded side of each disc was rated each week on a scale of 5 (shiny, glossy) to 1 (fully bloomed). These data are presented in Tables 4 and 5 for coatings made with FHPKO and FPKO (both with 2.5% HPO added), respectively.

Five main conclusions can be drawn from these bloom data: (1) FHPKO coatings bloomed faster than FPKO coatings; (2) addition of milk fat increased the bloom rate compared to the control; (3) addition of CB increased the bloom rate, but only slightly; (4) increasing addition levels increased bloom rate for coatings made with milk fat; (5) coatings made with WAMF bloomed significantly slower than those with added SAMF for FHPKO coatings at 10% replacement.

Correlation of binary mixtures to compound coatings. The qualitative measure of eutectic formation by using isosolid diagrams did not seem to correlate with rate of bloom formation or hardness of compound coatings. When eutectic formation occurred in a binary mixture, the analogous compound coating, prepared with the same fat composition, was soft. However, the converse was not necessarily true; when soft coatings were manufactured, eutectic formation was not always observed in corresponding binary mixtures. For example, when ICCB was added to FHPKO, a significant eutectic was observed in the binary mixture, while coatings made with these fats were soft and bloomed slowly. However, the addition of SAMF to FHPKO resulted in only minimal eutectic formation in the binary mixture, although the coatings were soft and bloomed rapidly. Apparently, factors other than eutectic formation affect hardness and bloom rate in compound coatings.

The relationship between hardness of compound coatings, as measured by penetration depth, and SFC at 25°C of binary mixtures with the same fat composition is shown

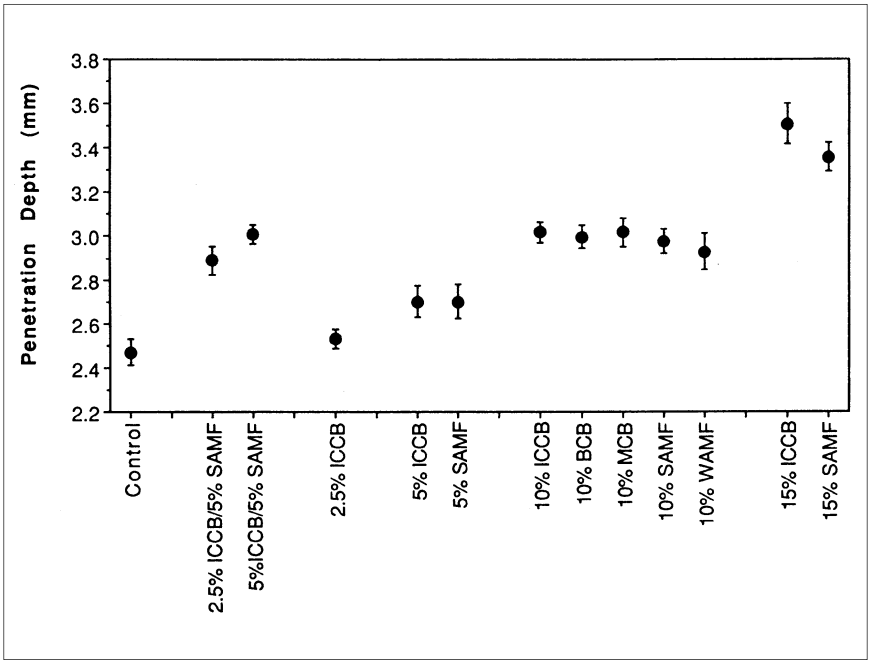

FIG. 7. Penetration depth in compound coatings made with FHPKO with substitution of cocoa butters (Brazilian, BCB; Malaysian, MCB; Ivory Coast, ICCB) or milk fats (SAMF; WAMF). See Figures 1 and 3 for abbreviations.

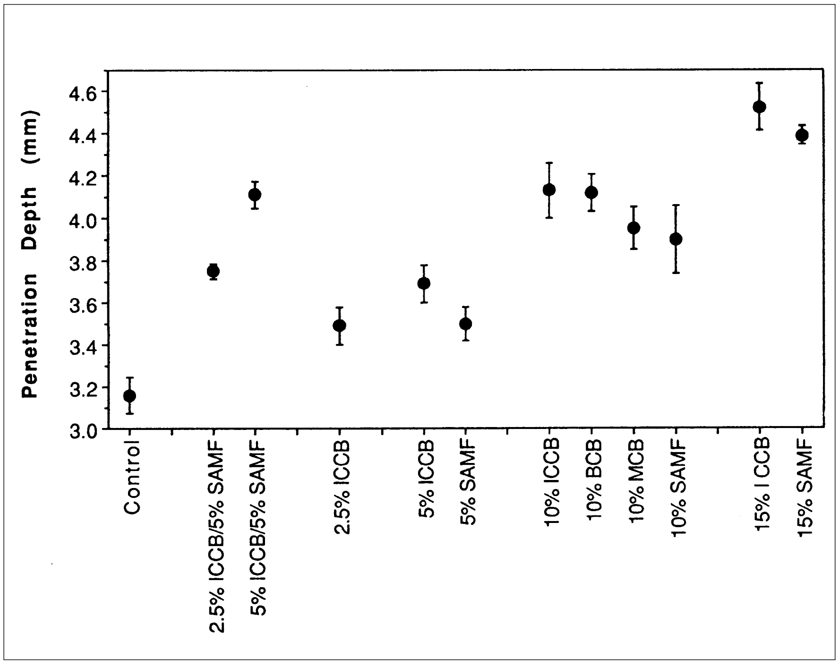

FIG. 8. Penetration depth in compound coatings made with fractionated palm kernel oil (FPKO) with substitution of cocoa butters (BCB, MCB, ICCB) or milk fats (SAMF, WAMF). Figures 3 and 7 for abbreviations.

TABLE 4
Bloom Development at Ambient Conditions for Fractionated, Hydrogenated Palm Kernel Oil with 2.5% Fully Hydrogenated Palm Oil Replacements of Cocoa Butter and Anhydrous Milk Fat

	Weeks																					
Coating[a]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
FHPKO Control	4[b]	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	2	2	2	1
2.5/5% ICCB/SAMF	4	4	4	4	4	4	4	3	3	3	2	2	1									
5/5% ICCB/SAMF	4	4	4	4	4	4	4	3	3	3	3	2	2	2	2	1						
2.5% ICCB	4	4	4	4	4	4	4	4	4	4	3	3	3	3	2	2	2	2	1			
5% ICCB	4	4	4	4	4	4	4	3	3	3	3	3	2	2	2	2	2	2	1			
5% SAMF	4	4	4	4	4	4	4	3	3	3	2	2	1									
10% ICCB	4	4	4	4	4	4	4	3	3	3	3	2	2	2	2	2	1					
10% MCB	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	2	1				
10% BCB	4	4	4	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		
15% ICCB	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	2	2	1		
15% SAMF	4	4	4	4	3	3	2	2	1													

[a]Control, full FHPKO. For abbreviations, see Table 1.

[b]Subjective scores given for bloom: 4 = slightly dull; 3 = dull, traces of bloom; 2 = partly bloomed, appearance not acceptable; 1 = complete light bloom.

TABLE 5
Bloom Development at Ambient Conditions for Fractionated Palm Kernel Oil with 2.5% Fully Hydrogenated Palm Oil Replacements of Cocoa Butter and Anhydrous Milk Fat

	Weeks																											
Coating[a]	0	2	4	5	7	9	11	13	15	17	19	21	23	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
FHPKO Control	4[b]	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	1				
2.5/5% ICCB/SAMF	4	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1						
5/5% ICCB/SAMF	4	4	4	4	4	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1						
2.5% ICCB	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	2	2	2	2	2	1				
5% ICCB	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	2	2	2	1
5% SAMF	4	4	4	4	4	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	1		
10% ICCB	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	
10% MCB	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	2	2									
10% BCB	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	2	2									
10% SAMF	4	4	4	4	4	4	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	1					
15% ICCB	4	4	4	4	4	4	4	4	3	3	2	2	2	2	2	2	2	2	2	2	2	2						
15% SAMF	4	4	4	4	4	3	3	3	3	3	3	3	3	2	1													

[a]Control, full FHPKO. For abbreviations, see Table 1.

[b]Subjective scores: See Table 4 for scoring code.

in Figure 9. Data points correspond to all binary mixtures for which compound coatings were manufactured. Data included are 10% addition levels of CB and milk fats to both FHPKO and FPKO, because there were no trends observed related to type of PKO used. SFC at 25°C, as a measure of hardness for binary mixtures, increased as hardness of actual compound coatings with the same fat composition increased. Thus, SFC of a fat mixture at 25°C can be used as

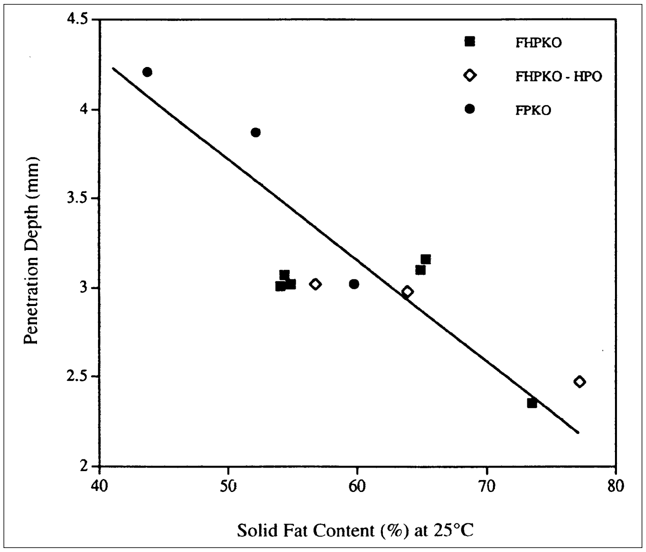

FIG. 9. Comparison of penetration depth in compound coatings (hardness) and solid fat content at 25°C of a binary mixture of the same composition of fats. Data points show various mixtures of cocoa butters or milk fats with FHPKO, FHPKO with 2.5% addition of hydrogenated palm oil (HPO) as nucleator, or FPKO. See Figures 1 and 8 for abbreviations.

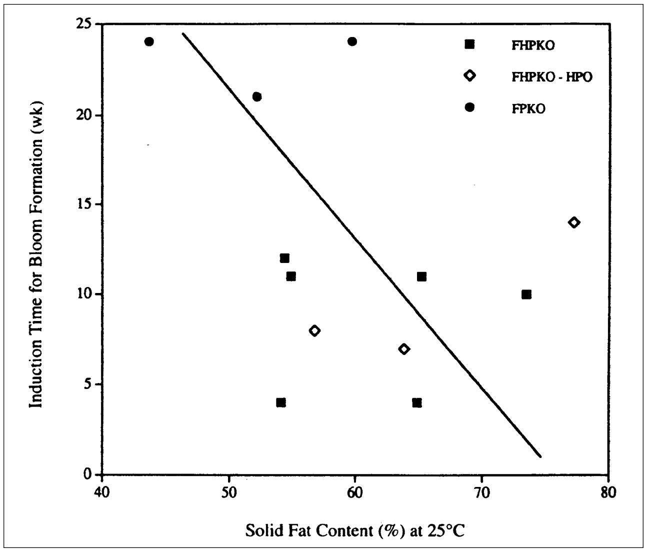

FIG. 10. Comparison of induction time for bloom formation in compound coatings during storage at ambient conditions and solid fat content at 25°C of a binary mixture of the same composition of fats. Data points show various mixtures of cocoa butters or milk fats with fractionated, FHPKO, FHPKO with 2.5% addition of HPO as nucleator, or FPKO. See Figures 1, 8, and 9 for abbreviations.

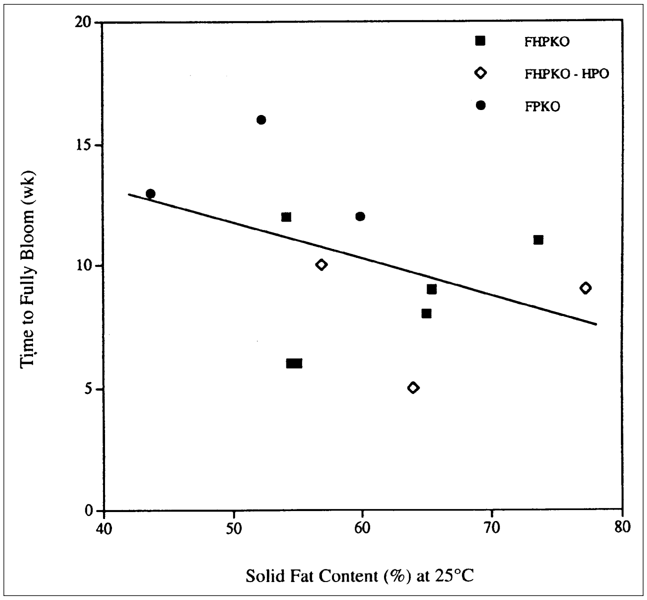

FIG. 11. Comparison of rate of bloom formation in compound coatings during storage at ambient conditions and solid fat content at 25°C of a binary mixture of the same composition of fats. Data points show various mixtures of cocoa butters or milk fats with FHPKO, FHPKO with 2.5% addition of HPO as nucleator, or FPKO. See Figures 1, 8, and 9 for abbreviations.

a reasonable indicator of hardness of coatings made with that fat composition.

SFC at 25°C for binary mixtures was also correlated to bloom formation in compound coatings. Two measures of bloom formation were used. The induction time for bloom formation was the time during which the sample remained at the initial bloom rating. The time to full bloom was the time from the first appearance of bloom until the rating reached the lowest value of one. Despite low correlation coefficients, induction time for bloom formation and time to full bloom generally decreased as SFC at 25°C increased (Figs. 10 and 11). Also, FHPKO coatings (which were harder) bloomed faster than FPKO coatings (which were softer). It was also observed, however, that as the addition level of a particular fat increased, the coating became softer, yet bloomed faster.

The trend of harder coatings to bloom more rapidly is the reverse of that expected in tempered chocolate, where harder chocolates typically bloom more slowly. Apparently, the mechanisms of importance in bloom formation in chocolate, such as polymorphic transitions and phase separation, are not the same in these compound coatings. In particular, bloom formation in coatings cannot be attributed to polymorphic transitions, because the X-ray data clearly show that fat mixtures made with milk fat and PKO do not undergo polymorphic transitions. Fat mixtures of CB and PKO did undergo polymorphic transition when the CB content was greater than 40%. However, these levels were not reached in the coatings made in this study, and thus, polymorphic transitions cannot explain formation of bloom in these coatings.

An interesting anomaly in these results is the difference in bloom formation in coatings made with WAMF and SAMF. Despite having nearly similar chemical composition and melting point, coatings made with WAMF were significantly more resistant to bloom formation than those made with SAMF. One possible explanation for these observations may be differences in composition of nontriglyceride lipids (such as mono- and diglycerides, fatty acids, sterols, etc.) between these milk fats. It is well known that mono- and diglycerides have substantial impact on lipid crystallization rates and may influence the mechanisms of bloom formation in this case.

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