

DAIRY FOODS

Incorporation of Milk Fat and Milk Fat Fractions into Compound Coatings Made from Palm Kernel Oil

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ABSTRACT

The potential of incorporating anhydrous milk fat and milk fat fractions into compound coatings based on palm kernel oil was investigated. Fractionation of milk fat by melt crystallization was utilized to prepare five fractions with different melting profiles. The anhydrous milk fat and milk fat fractions were added at 5, 10, and 15% of the fat phase in compound coatings made with palm kernel oil. Fats were analyzed for fatty acid and triacylglycerol profiles, solid fat content, thermal profile, and melting point. Coatings that were made with the addition of anhydrous milk fat or milk fat fractions were generally softer than the control coating, although hardness depended on the melting point of the added milk fat fraction. Coatings made with fractionated, hydrogenated palm kernel oil developed fat bloom (the whitish haze that forms on a chocolate surface) faster than coatings made with fractionated palm kernel oil during storage at ambient conditions. As hardness increased, induction time for bloom formation and time to full bloom decreased. Binary mixtures of palm kernel oil and milk fat exhibited diluent mixing effects and contained only β' polymorph crystals.

(**Key words:** compound coatings, palm kernel oil, milk fat fractions, fat bloom)

Abbreviation key: **AMF** = anhydrous milk fat, **FPKO** = fractionated PKO, **FHPKO** = fractionated hydrogenated PKO, **HPO** = hydrogenated palm oil, **PKO** = palm kernel oil, **S** = solid, **SAMF** = summer AMF (used in fraction designations), **SFC** = solid fat content, **WAMF** = winter AMF.

INTRODUCTION

The utilization of milk fat fractions provides potential benefits in a variety of products, and unique

properties are imparted by fractions optimized for their use. Confectionery products, specifically, may benefit from the increased milk flavor and the rich, creamy texture of milk fat. Typically, milk fat fractions have been utilized in chocolates to inhibit fat bloom (the formation of a white haze on the surface of a chocolate coating) and to provide other functional benefits (15). However, compound coatings are another large segment of the confectionery industry that could potentially benefit from application of milk fat fractions (11).

Compound coatings are an inexpensive replacement for chocolate and command a large share of the confectionery industry (19). High quality coatings are generally based on palm kernel oil (**PKO**) as the main fat phase because PKO mimics many of the desired qualities of cocoa butter, especially when correctly modified. However, past efforts have shown that fats with high lauric acid content, such as PKO, have limited compatibility with milk fat, making them more susceptible to softening and fat bloom (13).

Compound coatings generally lack true chocolate flavor because of the use of low fat (10 to 12% cocoa butter) or nonfat cocoa powder instead of cocoa liquor (50% cocoa butter) and the use of nonfat milk powder instead of whole milk powder. Significant flavor and, perhaps, textural benefits could be obtained in PKO-based coatings if anhydrous milk fat (**AMF**) or milk fat fractions with specific melting and flavor profiles could be added at percentages that would be sufficient without causing incompatibilities such as softening effects and enhanced fat bloom.

Bigalli (2) studied interactions between AMF and PKO by generating mixture diagrams based on solid fat content and demonstrated that these fats were essentially compatible because they did not show eutectic softening. Hogenbirk (13) found that mixtures of a fractionated, hydrogenated palm kernel oil (**FHPKO**) with milk fat exhibited the least amount of softening compared with Malaysian cocoa butter, Brazilian cocoa butter, and a cocoa butter extender. Despite this, milk fat is still reputed to soften coatings and enhance fat bloom.

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Our objective was to investigate the effects of incorporating AMF and milk fat fractions into two different compound coatings based on PKO using both subjective and objective measures. These results were compared with the results for full PKO controls for each type of coating. Furthermore, all fats were characterized for fatty acid and triacylglycerol profiles, solid fat content, thermal profile, and melting point. Phase behavior of mixtures of PKO with AMF and its fractions was investigated to understand more completely the extent of incompatibilities between these fats.

MATERIALS AND METHODS

Fractionation of Milk Fat

The AMF from the summer feeding period (**SAMF**) (Level Valley Dairy, West Bend, WI) was thermally fractionated by the method of Grall and Hartel (10). Liquid fractions from the high melting solid fractions obtained at 32, 30, and 28°C were combined and sequentially refractionated to obtain middle and low melting fractions at 21 and 17°C, respectively. A superstearin fraction was produced using a two-step process. During the first step, the SAMF was fractionated at 25.5°C to produce a high melting solid fraction. During the second step, the solid (**S**) fraction from the 25.5°C fractionation was refractionated at 38°C to produce a very high melting solid fraction. Five solid fractions, referred to by their fractionation temperature as 25.5/38S, 30S, 28S, 21S, and 17S, were evaluated. Sufficient quantities of each fraction were produced to provide a uniform starting material for all experiments in this study.

Analysis of Fat Samples

Gas chromatographic analysis of fatty acid composition was accomplished by conversion to butyl esters using a modified method of Iverson and Sheppard (14) (Varian Model 3400; Varian Association, Palo Alto, CA). Triacylglycerol profiles were determined by gas chromatography (Varian DS 651, Varian Association) using a modified method of Lund (18).

Solid fat content (**SFC**) profiles for each fat or fat mixture were generated utilizing a Bruker Minispec unit equipped with on-board software for data processing (Bruker, Milton, ON, Canada). The 10-mm diameter nuclear magnetic resonance tubes were filled with approximately 20 to 25 mm of fat. The tubes were capped and tempered according to a modified method Cd 16-81 of the American Oil Chemists' Society (1), which specifies a thermal pro-

file 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°C before data are read. The SFC was determined at the following temperatures: 0, 5, 10, 15, 20, 25, 30, 32.5, 40, 45, 50, and 60°C. Each fat was evaluated in duplicate, with three SFC readings for each on two different days, and a mean SFC was calculated. The SFC data for binary mixtures with different ratios of PKO to AMF and its fractions were generated, and isosolid diagrams (temperature as a function of composition) were created to evaluate the compatibility of the fats. Isosolid diagrams were plotted by interpolation between SFC points using cubic splines to find temperature for a constant SFC over the range of composition.

Thermal profiles were generated using a Perkin-Elmer differential scanning calorimeter (DSC 7; Perkin-Elmer Corporation, Norwalk, CT). The calorimeter was calibrated at two temperatures using indium and mercury. The AMF, 17S, 21S, and 28S samples were heated to 60°C and held for 3 min to erase crystalline memory, cooled to -60°C at 10°C/min, held for 3 min to induce crystallization, and reheated to 60°C at 10°C/min to record a melting curve. The higher melting fraction, 25.5/38S, was heated to 75°C and held for 3 min to erase crystalline memory, cooled to -60°C at 10°C/min, held for 3 min to induce crystallization, and reheated to 75°C at 10°C/min to record a melting curve. The PKO and HPO were heated to 80°C and held for 5 min to erase crystalline memory, cooled to -20°C at 5°C/min, held for 5 min to induce crystallization, and reheated to 80°C at 5°C/min to record a melting curve (21). Thermal profiles for binary mixtures of fats were generated by heating tempered fat mixtures from -20°C to 60°C at 5°C/min. Melting (or clear) points were determined using a capillary technique [AOCS method Cc 1-25 (1)].

Polymorphic structure of binary mixtures of fats was investigated using a Nicolet I₂V Polycrystalline X-ray Diffraction System (Nicolet Instrument Corp., Madison, WI) and Siemens Polycrystalline Software Package (Micro-VAX release 2.41; Siemens Industrial Automation, Inc., Madison, WI). The mixtures were melted at 60°C and placed in each x-ray sample disk. Samples were tempered according to a modified version of the AOCS method CD 16-81 (1). Following 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 angles (2θ) of 5 to 35°, and molecular spacings were calculated by the accompanying software. Relative intensities of the detected peaks were used to determine polymorphic structure (16).

Preparation of Coating Samples

The SAMF, AMF from the winter feeding period (**WAMF**) (Level Valley Dairy, West Bend, WI), and the five milk fat fractions were incorporated into two chocolate-flavored compound coatings made with PKO. These coatings (with reduced fat of about 26%) were made from either FHKPO or fractionated palm kernel oil (**FPKO**) and were supplied by Abitec Co. (Columbus, OH) and Loders Croklaan (Lisle, IL), respectively. Compound coating samples were prepared by addition of AMF or a milk fat fraction plus 2.5% (fat basis) of a fully hydrogenated palm oil (**HPO**) as a crystallization starter to the low fat base. The PKO replacement levels were 5, 10, and 15% for SAMF and each of the five milk fat fractions. The WAMF was added only at 10% in the FHPKO coating. The appropriate PKO was then added to bring the total fat content of the low fat base to the desired level of 33.4%. Full PKO control coatings were prepared for both types of coatings. Because of the large number of samples evaluated, only one replicate of each coating was produced.

The appropriate amount of replacement fat was mixed with each coating sample (400 to 500 g of unfinished base) and held for 1 h at 60°C. To ensure homogeneity, the crystallization starter, HPO, was melted and mixed together with added fats before being added to the unfinished base at 60°C. The coating was then cooled to a few degrees above the melting point of the PKO: FHPKO to 35.5°C and FPKO to 40.5°C. Once cooled, the coating was poured into warmed 12-cavity disc molds (5.1 cm diameter × 0.62 cm thick) made of polycarbonate plastic (Tomric Plastics, Buffalo, NY). The molds were cooled rapidly at 7°C for 30 min with high air velocity, and coatings were held at 18°C for further testing.

Analysis of Coating Samples

Some subjective parameters of the coatings were evaluated by the researchers at room temperature (22°C) and were based on a five-point scale (5 = excellent to 1 = poor). Contraction was evaluated on the release of coating discs from the mold upon inversion (5 = sample simply fell from mold upon inversion to 1 = manual removal). Gloss was based on shininess of both molded and unmolded sides of the coating sample (5 = smoothness of a glass tile to 1 = very dull). Snap was evaluated by breaking the coating disc between the fingers (5 = very hard, crisp snap to 1 = soft, no snap). Finally, internal structure was evaluated by looking at the cross-section of the broken sample (5 = fine grained, small crystal size to 1 =

coarse grained, large crystal size, crumbly in texture).

In addition, an informal sensory panel of 15 students was used to evaluate the molded coating samples. Snap, gloss (of unmolded side), color, cocoa butter flavor, butter flavor, melt-in-the-mouth, melt-in-the-hand, and overall preference were rated on a structured, nine-point hedonic scale.

The Casson plastic viscosity and yield value of the molten coatings were determined by a method endorsed by the Viscosity Subcommittee of the Chocolate Manufacturers Association, and National Confectioners Association (7). Rheological parameters of the melted coatings were determined at 40°C using a viscometer (HA Series Brookfield viscometer with a SC4-27 small sample adapter; Brookfield Engineering Laboratories, Stoughton, MA).

Penetration depth, which is related to hardness, was measured using a penetrometer (Universal Penetrometer model 73510; Precision Scientific Petroleum Instruments Company, Bellwood, IL) according to the British Standard Method BS 684: Section 1.11: 1976, Method 2 (3). The hardness of binary mixtures of fats was defined by the SFC at 25°C, found by analysis of the SFC profiles.

Fat bloom was evaluated during storage at ambient conditions. At ambient conditions, 22°C averaged over 10 mo, two discs of each sample were placed on aluminum foil, unmolded side down, and large pieces of aluminum foil were used to loosely cover the coatings. All samples were evaluated visually once a week on both sides for the appearance of bloom. The following visual evaluation code was used in the study: 5 = very glossy; 4 = slightly dull, no gloss; 3 = dull, traces of bloom; 2 = partly bloomed (appearance not acceptable); and 1 = full bloom. 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 1.

RESULTS AND DISCUSSION

Analysis of Fat Samples

Table 1 shows the fatty acid profiles for the AMF, milk fat fractions, PKO, and HPO used in this study. A distinct difference was found between milk fats; SAMF contained more than twice as much short-chain (C_{4:0} to C_{8:0}) and medium-chain (C_{10:0} to C_{12:0}) fatty acids, but WAMF had more long-chain saturated (C_{16:0} to C_{18:0}) fatty acids. The fatty acid profiles for milk fat fractions, which were made from

TABLE 1. Fatty acid profile of palm kernel oils, palm oil, milk fats, and milk fat fractions.¹

Fatty acid	FHPKO	FPKO	HPO	(mol/100 mol)						
				WAMF	SAMF	17S	21S	28S	30S	25.5/38S
C _{4:0}				2.7	5.1	6.3	3.4	3.1	3.2	2.6
C _{6:0}				0.7	2.8	3.0	1.9	1.7	1.7	1.4
C _{8:0}	1.0	1.0		0.4	1.6	1.5	1.2	1.0	1.0	0.9
C _{10:0}	1.9	1.8		1.4	3.2	2.5	2.9	2.4	2.5	2.0
C _{12:0}	49.9	47.7	0.2	2.4	3.4	2.1	3.7	3.2	3.2	2.8
C _{14:0}	22.9	22.6	0.9	10.4	11.2	8.3	13.0	12.1	12.4	12.2
C _{14:1}				0.4	0.3	0.2	0.3	0.3	0.3	0.3
C _{16:0}	9.9	10.1	42.5	34.7	29.4	37.5	34.4	36.1	37.6	39.4
C _{16:1}				1.5	1.4	1.0	1.1	0.9	0.9	0.8
C _{18:0}	9.1	3.7	55.9	16.4	12.6	16.9	15.0	18.0	18.0	21.1
C _{18:1}	3.7	8.9		24.7	25.3	18.1	20.3	18.5	16.8	14.4
C _{18:2}	1.5	3.9		3.5	3.2	2.2	2.4	2.4	2.1	1.9
C _{18:3}				0.7	0.6	0.5	0.5	0.5	0.4	0.4
C _{10:0}	0.2	0.2	0.6							

¹Fractionated, hydrogenated palm kernel oil (FHPKO), fractionated palm kernel oil (FPKO), fully hydrogenated palm oil (HPO), winter anhydrous milk fat (WAMF), summer anhydrous milk fat (SAMF), and milk fat fractions; solid (S) fractions were 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).

SAMF, followed a general trend of decreasing levels of long-chain saturated fatty acids and increasing levels of long-chain unsaturated (C_{16:1} to C_{18:1} to C_{18:2}) and short-chain (C_{4:0} to C_{8:0}) fatty acids with decreasing fractionation temperature. These results are in agreement with trends found in previous work (6, 17). Irregularities were noted in the 17S fraction, for which concentrations of long-chain saturated fatty acids were higher than expected, and concentrations of C_{18:1} and C_{18:2} were lower than expected. Modified PKO contained 40 to 50% lauric acid (C_{12:0}). The most distinct difference between the two PKO was the amount of C_{18:0}, which was increased in FHPKO because of the hydrogenation. The HPO, which was fully hydrogenated, consisted of only saturated fatty acids, as expected, and was 98% C_{16:0} and C_{18:0}. The composition of PKO and HPO agreed with reported values (8, 21).

Table 2 shows the triacylglycerol profiles for AMF, milk fat fractions, PKO, and the hardened palm oil used in this study. The SAMF was higher in C₂₆ to C₃₈, and WAMF was higher in C₄₄ to C₅₄. The milk fat fractions contained lower levels of high molecular weight triacylglycerols (C₄₆ to C₅₄) and higher levels of middle molecular weight triacylglycerols (C₃₄ to C₄₂) as fractionation temperature decreased. All fractions, except 17S, showed a moderate increase in levels of low molecular weight triacylglycerols (C₂₆ to C₃₂), compared with the original milk fat, SAMF. The intermediate melting fraction, 21S, showed the greatest increase in C₄₄, which has also been reported by others (15). The PKO were concentrated in middle molecular weight triacylglycerols (C₃₄ to C₄₀). The HPO contained 91% high molecular weight triacylglycerols (C₄₈ to C₅₄), which corresponded with the

large concentration of palmitic (C_{16:0}) and stearic (C_{18:0}) acids.

The SFC profiles of each fat sample are shown in Figure 1. The AMF and milk fat fractions had more gradual melting profiles than did the PKO. The SAMF had slightly lower solid fat than WAMF at all temperatures. Both SAMF and WAMF had less solid fat at all temperatures than did the milk fat fractions, except for 17S after 20°C when rapid melting began. The 25.5/38S, 30S, 28S, and 21S fractions had simi-

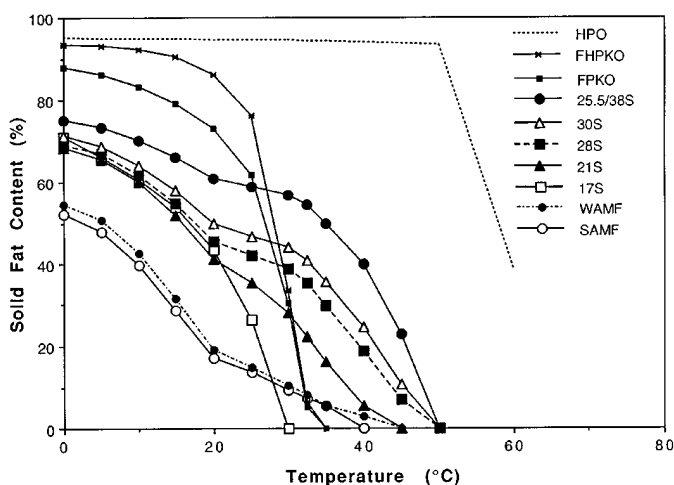


Figure 1. Curves of solid fat content for summer anhydrous milk fat (SAMF) and winter anhydrous milk fat (WAMF). Solid (S) milk fat fractions were obtained at 17°C (17S), 21°C (21S), 28°C (28S), 30°C (30S), and 25.5°C and then at 38°C (25.5/38S). FHPKO = Fractionated, hydrogenated palm kernel oil, FPKO = fractionated palm kernel oil, and HPO = fully hydrogenated palm oil.

TABLE 2. Acyl carbon number profile of palm kernel oils, palm oil, milk fats, and milk fat fractions.¹

Acyl carbon number	FHPKO	FPKO	HPO	WAMF	SAMF	17S	21S	28S	30S	25.5/38S
C ₂₆	1.7	1.6		0.3	1.2	1.2	2.7	2.8	1.8	1.3
C ₂₈	2.3	2.0		0.5	1.6	1.3	2.9	3.2	2.3	2.3
C ₃₀	1.9	1.8		1.1	1.9	1.8	3.5	2.8	2.0	1.9
C ₃₂	4.8	4.7		2.1	3.1	2.3	3.0	2.9	2.3	2.0
C ₃₄	7.5	7.3	1.0	5.6	6.5	6.0	5.5	5.0	4.2	3.7
C ₃₆	26.9	25.8	0.5	10.8	11.7	15.8	8.8	8.2	7.4	6.2
C ₃₈	22.4	22.1	3.1	13.4	13.8	18.3	10.1	9.5	8.6	7.2
C ₄₀	12.7	13.0	1.8	10.7	10.6	11.6	9.4	7.7	7.2	5.9
C ₄₂	8.0	8.4		6.6	6.6	6.8	7.2	6.0	5.9	5.2
C ₄₄	4.3	4.6		6.2	5.8	4.9	7.4	6.8	7.1	6.8
C ₄₆	2.5	2.9	2.8	6.7	6.4	4.4	7.9	8.7	9.7	10.6
C ₄₈	2.2	2.4	11.0	8.7	7.8	5.5	9.5	10.7	12.4	14.2
C ₅₀	1.2	1.0	37.3	11.1	9.7	8.7	10.6	12.5	14.3	16.6
C ₅₂	1.0	1.0	32.1	10.7	8.6	7.6	8.1	9.0	10.7	11.8
C ₅₄	0.8	1.3	10.5	5.6	4.9	3.7	3.6	4.4	4.2	4.3

¹Fractionated, hydrogenated palm kernel oil (FHPKO), fractionated palm kernel oil (FPKO), fully hydrogenated palm oil (HPO), winter anhydrous milk fat (WAMF), summer anhydrous milk fat (SAMF), and milk fat fractions; solid (S) fractions were 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).

larly shaped SFC curves, each slightly lower in solid fat as fractionation temperature decreased. The FHPKO had higher SFC at lower temperatures and had a sharper melting profile than did FPKO. The high SFC for FHPKO at room temperature (22°C) provided good snap, and the sharp melting leaves no waxy residue in the mouth, making FHPKO a slightly better quality coating than FPKO. The HPO ex-

hibited little to no melting between 0 and 50°C, which made it an excellent crystallization starter.

Figure 2 shows the thermal analyses, from differential scanning calorimetry, of tempered milk fat samples that had been stored for at least 13 wk at 13°C. The thermal profiles for SAMF and WAMF revealed the presence of three distinct melting regions, which were similar to those found in previous research (6, 10, 17, 24). The three major peaks are due to three major groups of glycerides (low, middle, and high) melting independently, and their relative size and position varies with thermal history and triacylglycerol composition (9). The melting curves of the milk fat fractions followed a trend that was expected based on previous research (6, 9, 17, 24). The highest melting fraction (25.5/38S) contained mostly high melting component, and the thermal peaks shifted to lower temperatures as fractionation temperature of each fraction decreased.

The spontaneous crystallization of PKO in a stable β' form confirms, with reasonable certainty, that the single peak PKO thermograms (not shown) represented melting of the β' polymorph (20). The x-ray diffraction of tempered PKO indicated a β' polymorph as well. The melting curve of HPO was very different from all the other curves; it had two sharp peaks and a definite exotherm where the scan crossed below the baseline. A refined, unmodified palm oil would show many peaks and related exotherms, especially at the low scanning rate of 5°C/min, indicating that significant structural reorganization was occurring during the DSC scan (5). However, there were

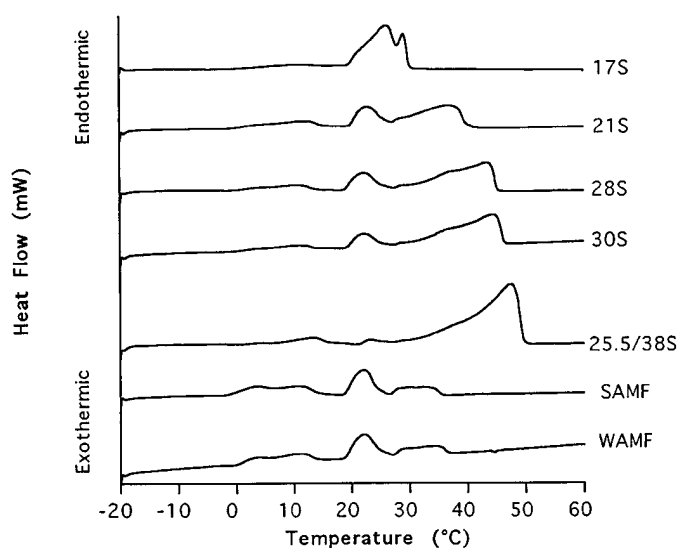


Figure 2. Melting curves shown by differential scanning calorimetry (5°C/min) for tempered summer (SAMF) and winter anhydrous milk fat (WAMF). Solid (S) milk fat fractions were obtained at 17°C (17S), 21°C (21S), 28°C (28S), 30°C (30S), and 25.5°C and then at 38°C (25.5/38S).

only two peaks and one exotherm in the HPO heating scan, mainly because of the high degree of hydrogenation, which has been found to inhibit completely the recrystallization to the highly ordered β polymorph, allowing only the β' polymorph to form (4). The first peak in the HPO scan was most likely the lower melting α polymorph. The exotherm indicated rearrangement of this α polymorph into a new crystal form, β' , which melted to give the second peak (4).

Table 3 shows the melting points of the fat samples in this study. The WAMF (36.8°C) had slightly higher melting point than SAMF (34.5°C), reflected by the higher content of palmitic and stearic acids (Table 1). Melting points of milk fat fractions decreased as fractionation temperature decreased. The two PKO were selected such that their melting points were essentially the same (Table 3). The HPO had significantly higher melting point (58.8°C), which makes it useful as a crystal nucleator in PKO coatings.

Analysis of Coating Samples

Several coating samples—a full PKO control, 10% replacement level of SAMF, and 10% replacement of 21S for each type of PKO coating—were evaluated using an informal sensory panel. No differences in snap were found between the two controls and their corresponding 10% replacement coatings. However, coatings made with FPKO were softer than coatings made with FHPKO, as expected from the SFC curves. Overall, no differences in sensory analysis for gloss, color, cocoa flavor, butter flavor, melt-in-the-mouth, melt-in-the-hand, and overall preference were found between any of the samples.

Several other subjective evaluations, made by the researcher, assessed the quality of the coatings made in this study. After 24 h at 18°C, samples were rated for gloss, and all were rated as either a 5 or 4 for the molded and unmolded sides, respectively. All samples were also rated as excellent (score of 5) for contraction from the mold. Snap and internal structure, however, were much more varied, depending on type of coating, type of replacement fat, and replacement level. The subjectively determined values for snap closely correlated with the penetrometer determination of hardness, as discussed later. The internal structure for all coatings made with FHPKO were rated as excellent (score of 5) and exhibited a fine grain. Coatings made with FPKO had scores ranging from 4 to 2 for internal structure. In general, the FPKO coatings were somewhat crumbly unless a harder milk fat fraction was added, such as the 28S,

30S, and 25.5/38S fractions. The coatings made with FPKO with the poorest internal structure (score of 2) were those made with 10 and 15% replacement of the 17S milk fat fraction.

Values for Casson plastic viscosity and yield were determined for each compound coating sample at 40°C. There were no differences in the plastic viscosity or yield value corresponding to levels or type of replacement fat. The PV for coatings made with FHPKO ranged from 9.7 to 16.3 P (poise), and those made with FPKO ranged from 8.0 to 12.8 P. For a molding coating, viscosity should range from 10 to 20 P (12). Total fat, particle size, and particle size distribution have the greatest effect on the untempered viscosity (23). Because all of the coatings had the same total fat content, plastic viscosity would not be expected to change dramatically. Any differences in particle size between the coatings, which was not measured, did not influence the plastic viscosity.

The data for yield value were more scattered than those for plastic viscosity; values were between 33 and 41 dynes/cm² for coatings made with FHPKO and 3 to 17 dynes/cm² for coatings made with FPKO. In general, optimal yield value is 10 to 20 dynes/cm² for coatings used for molding but can increase to as much as 135 dynes/cm² (12), depending on the fat content, lecithin percentage, extent of grinding, and processing procedures (23). The influence of these factors is apparent from the differences in yield values between coating types because these coatings were produced by different manufacturers, under different conditions.

TABLE 3. Capillary melting point.

Sample ¹	Clear point ²	
	— (°C) —	
	\bar{X}	SD
SAMF	34.5	0.1
WAMF	36.8	0.1
17S	28.7	0.1
21S	39.2	0.1
28S	45.0	0.1
30S	46.0	0.1
25.5/38S	48.5	0.1
FHPKO	31.8	0.1
FPKO	31.7	0.1
HPO	58.8	0.1

¹Summer anhydrous milk fat (SAMF), winter anhydrous milk fat (WAMF), and milk fat fractions [solid (S) fractions were obtained at 17°C (17S), 21°C (21S), 28°C (28S), 30°C (30S), and 25.5°C then at 38°C (25.5/38S)], fractionated, hydrogenated palm kernel oil (FHPKO), fractionated palm kernel oil (FPKO), and fully hydrogenated palm oil (HPO).

²Three trials.

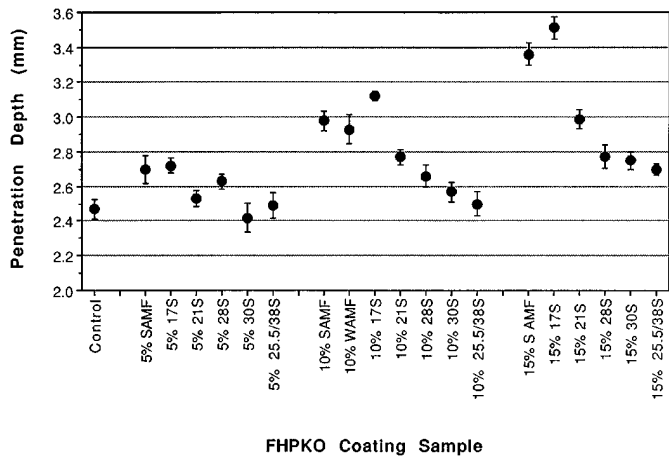


Figure 3. Penetration depths for all fractionated, hydrogenated palm kernel oil (FHPKO) coating samples: the control has only FHPKO. Summer anhydrous milk fat (SAMF), winter anhydrous milk fat (WAMF), and solid (S) milk fat fractions were obtained at 17°C (17S), 12°C (21S), 28°C (28S), 30°C (30S), and then at 38°C (25.5/38S). Error bars represent standard deviation of three sample measurements.

The hardness of compound coatings was measured by the depth of penetration of a needle into each coating. Increased penetration depth corresponds to increased coating softness. Because all compound coatings were produced in the same manner, differences in hardness were assumed to be due to addition of replacement fats. Figure 3 shows the mean penetration depths, with standard deviations, of coatings made with FHPKO and 2.5% HPO. All coatings were significantly softer than the control except for those made with 5% 21S, 5% 30S, and 5 and 10% 25.5/38S. The softest coatings were those made with 15% SAMF and 10 and 15% 17S. No differences between SAMF and WAMF were significant at the 10% level of addition. Clearly, the lower the melting point of the milk fat fraction and the higher the replacement level, the softer was the coating.

Figure 4 shows mean penetration depths, with standard deviations, for coatings made with FPKO and 2.5% HPO. All coatings were significantly softer than the control except for the coating made with 10% 25.5/38S. The softest coatings were coatings made with 15% 17S and 15% SAMF. Again, as the melting point of the milk fat fraction decreased, and, as replacement level increased, the softness of the coatings increased. However, for milk fat fractions with a very high melting point, such as 25.5/38S, even 15% replacement with this fraction did not result in substantial softening.

The SFC at 25°C for binary mixtures (hardness) is shown in Table 4. In general, SFC at 25°C varied

uniformly between values for the two pure components for either milk fat or milk fat fractions. A slight reduction in SFC at 25°C below the value of the milk fat or fraction for mixtures of greater than 50% of the milk fat component was observed. This result indicates the possibility of a slight eutectic incompatibility between these fats when the milk fat component was the predominant fat present in the mixture. Low levels of addition of milk fat components to PKO (5 to 10%) had little effect on SFC at 25°C. In addition, milk fat fractions with a higher melting point caused the least amount of softening of the PKO. Notably, the FPKO was significantly softer than the FHPKO at 25°C, and the addition of 2.5% HPO to FHPKO only increased SFC at 25°C by a few percentage points.

The softening of compound coatings as addition of milk fat increased was due to a dilution effect between binary mixtures of milk fat and PKO. The SFC, at all temperatures and for any mixture ratio, changed linearly between the SFC values for the two pure fats. This behavior is typical for two fats that demonstrate compatibility in melting behavior. A typical isosolid diagram showing this compatibility for mixtures of the 28S milk fat fraction and FPKO is shown in Figure 5. The melting curves (from differential scanning calorimetry) for this mixture also showed the gradual transition from melting behavior of one fat to melting behavior of the other (Figure 6), as would be expected for two compatible fats.

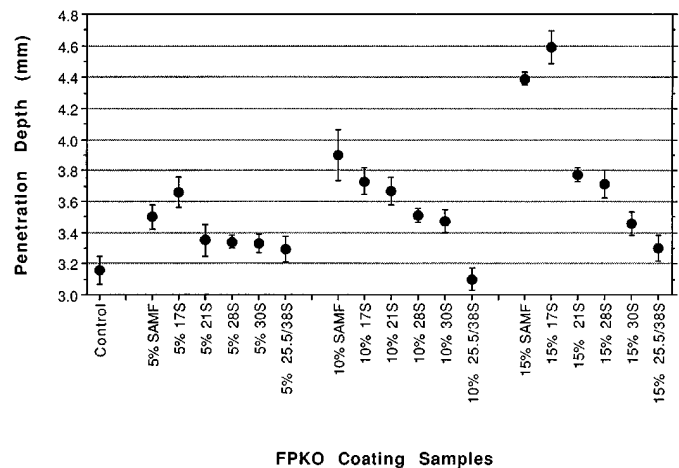


Figure 4. Penetration depths for all fractionated palm kernel oil (FPKO) coating samples: the control has only FPKO. Summer anhydrous milk fat (SAMF). Solid (S) milk fat fractions were obtained at 17°C (17S), 21°C (21S), 28°C (28S), 30°C (30S), and 25.5°C and then at 38°C (25.5/38S). Error bars represent standard deviation of three sample measurements.

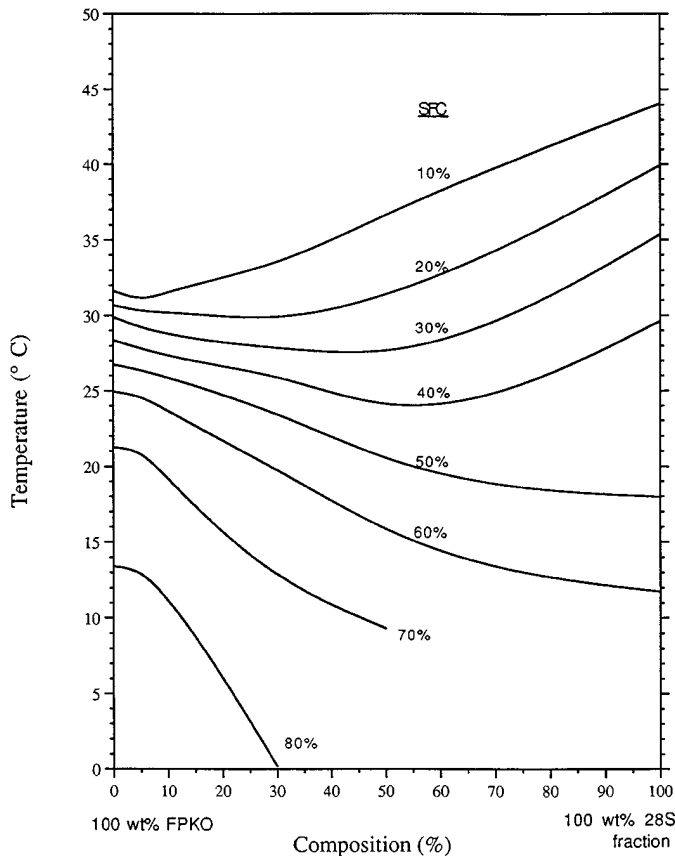


Figure 5. Isosolid diagram showing solid fat content (SFC) of binary mixtures of fractionated palm kernel oil (FPKO) and the solid (S) milk fat fraction obtained at 28°C (28S) expressed as weight percentage (g/100 g).

The softening that was exhibited between binary mixtures of either AMF or milk fat fractions and PKO was related to the softening in compound coatings made with similar composition of the fat phase. Figure 7 clearly shows the correlation between penetration depth in compound coatings and SFC at 25°C of the binary mixtures of fats used in the respective coating. As SFC at 25°C of the binary fat mixture increased, hardness (as inverse of penetration depth) of the compound coating decreased.

Fat bloom was evaluated at ambient conditions over a 10-mo period. The unmolded side of each coating, which was the side facing the bottom layer of aluminum foil, was used to evaluate bloom. The induction time for bloom formation was considered to be the time that each coating remained at its initial value. Bloom rate was estimated as the time required for the coating to reach a bloom value of 1, once bloom had begun.

Table 5 shows the subjective data for bloom development for coatings made with FHPKO and 2.5% HPO. Bloom formation of the control coating was the slowest. There was little difference between bloom rates of coatings made with SAMF and milk fat fractions. The coating made with 10% WAMF, however, had a much slower bloom rate than did coatings made with SAMF or milk fat fractions. The cause of this difference was not apparent. Perhaps slight differences in composition between SAMF and WAMF were responsible for this large difference in bloom rate. Especially at 15% replacement, coatings made with harder milk fat fractions, such as 28S and 30S, bloomed slightly faster. Coatings made with SAMF or milk fat fractions generally bloomed faster as replacement percentage increased.

Table 6 shows the subjective data for bloom development for coatings made with FPKO and 2.5% HPO. Coatings made with FPKO were substantially more resistant to bloom than those made with FHPKO. All coatings made with FPKO bloomed

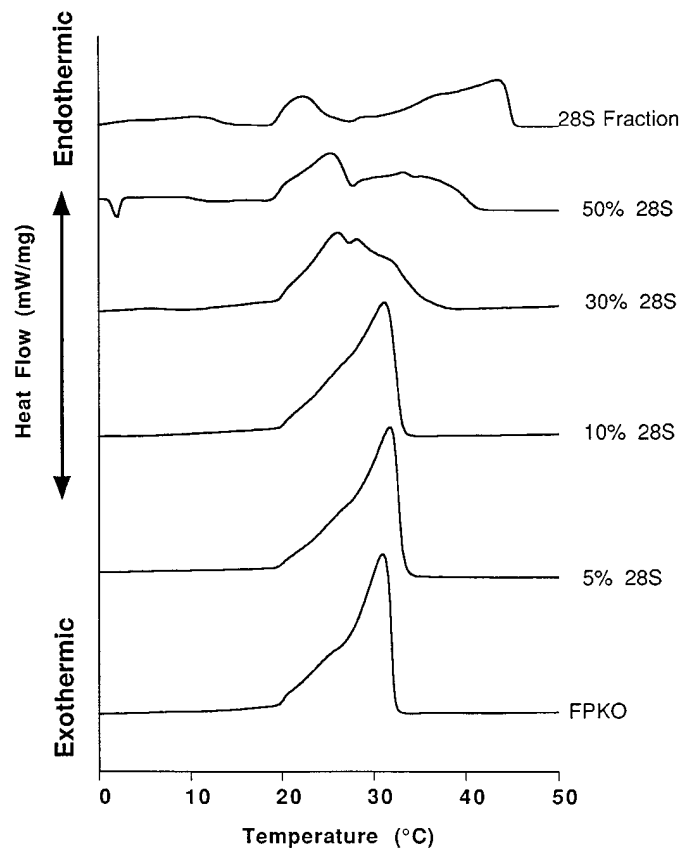


Figure 6. Melting curves shown by differential scanning calorimeter (5°C/min) of weight percentage (g/100 g) of mixtures of fractionated palm kernel oil (FPKO) and the solid (S) milk fat fraction obtained at 28°C (28S).

TABLE 4. Percentage of solid fat content at 25°C for binary mixtures of palm kernel oils with milk fat or milk fat fractions.¹

Fat addition	Addition					
	0%	5%	10%	30%	50%	100%
	FHPKO without HPO					
SAMF	73.5	72.2	64.9	40.5	23.3	11.7
WAMF	73.5	73.5	65.3	41.4	26.6	14.9
17S	73.5	69.3	63.2	38.4	21.1	26.6
21S	73.5	75.1	70.4	51.1	40.1	36.2
28S	73.5	73.0	68.1	52.6	42.4	42.8
30S	73.5	73.9	70.3	54.7	45.0	46.6
25.5/38S	73.5	75.1	71.8	57.7	51.4	58.9
	FHPKO with HPO					
SAMF	77.2		63.9	41.6	25.6	11.7
17S	77.2		63.7	38.9	24.3	26.6
28S	77.2		68.3	52.8	44.1	42.8
25.5/38S	77.2		69.8	58.9	53.0	58.9
	FPKO without HPO					
SAMF	59.8	57.8	52.2	31.9	19.6	11.7
17S	59.8	56.0	50.2	29.6	16.4	26.6
21S	59.8	59.6	55.1	41.8	33.6	36.2
28S	59.8	58.4	55.3	44.4	37.4	42.8
30S	59.8	60.6	57.7	45.9	40.3	46.6
25.5/38S	59.8	60.7	58.5	49.4	47.2	58.9

¹Summer anhydrous milk fat (SAMF); winter anhydrous milk fat (WAMF); solid (S) milk fat fractions obtained at 17°C (17S), 21°C (21S), 28°C (28S), 30°C (30S), 25.5°C and then at 38°C (25.5/38S); fractionated, hydrogenated palm kernel oil (FHPKO); fractionated palm kernel oil (FPKO); and fully hydrogenated palm oil (HPO).

TABLE 5. Bloom development at ambient conditions on coatings in which fractionated, hydrogenated palm kernel oil containing 2.5% fully hydrogenated palm oil was replaced by different amounts of anhydrous milk fat and milk fat fractions.

Coating ¹	Week																						
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
FHPKO Control	4 ²	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	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	3	3	3	3	3	2	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	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	1												
15% 21S	4	4	4	4	4	3	3	3	2	2	1												
15% 28S	4	4	4	3	3	3	2	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	1												

¹Control, fractionated, hydrogenated palm kernel oil (FHPKO), summer anhydrous milk fat (SAMF), winter anhydrous milk fat (WAMF), and solid 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).

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

TABLE 6. Bloom development at ambient conditions on coatings in which fractionated palm kernel oil containing 2.5% fully hydrogenated palm oil was replaced by different amounts of anhydrous milk fat and milk fat fractions.

Coating ¹	Week																																				
	0	2	4	6	8	10	12	14	16	18	20	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37										
FPKO (Control)	4 ²	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	2	1											
5% SAMF	4	4	4	4	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	1									
5% 17S	4	4	4	4	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	1														
5% 21S	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1															
5% 28S	4	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	2	2	2	1																
5% 30S	4	4	4	4	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	1																	
5% 25.5/38S	4	4	4	4	4	3	3	3	2	2	2	2	2	2	2	2	2	2	1																		
10% SAMF	4	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	1													
10% 17S	4	4	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1								
10% 21S	4	4	4	4	3	3	3	3	2	2	2	2	2	2	1																						
10% 28S	4	4	4	4	3	3	3	3	2	2	2	2	2	2	1																						
10% 30S	4	4	4	4	3	3	3	2	2	2	2	1																									
10% 25.5/38S	4	4	4	4	4	3	3	2	2	2																											
15% SAMF	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2	1																					
15% 17S	4	4	4	4	3	3	3	3	3	2	2	2	2	2	1																						
15% 21S	4	4	4	4	4	4	3	2	2	2																											
15% 28S	4	4	3	3	3	3	2	2																													
15% 30S	4	3	3	3	3	3	2																														
15% 25.5/38S	4	4	4	3	3	3	2	1																													

¹Control, fully fractionated palm kernel oil (FPKO), summer anhydrous milk fat (SAMF), and solid 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).

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

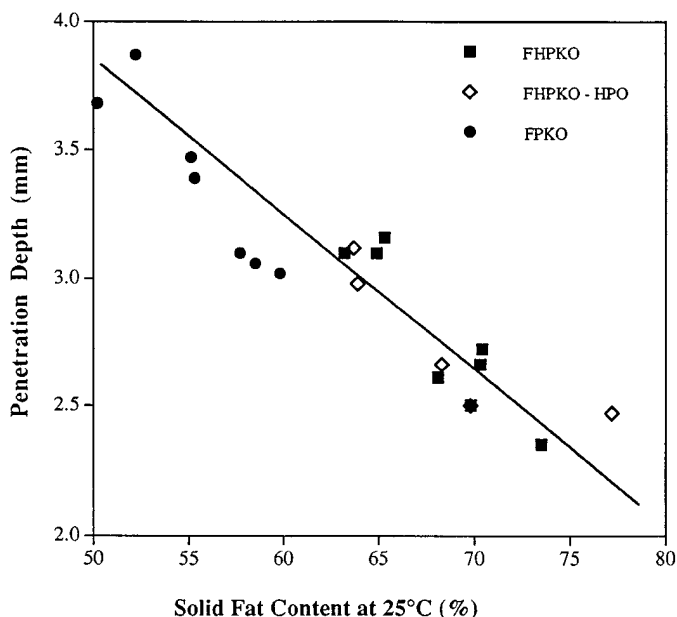


Figure 7. Comparison of penetration depth in compound coatings (hardness) and solid fat content at 25°C of a binary mixture of the same composition of fats. Data points show various mixtures of milk fats or milk fat fractions with fractionated, hydrogenated palm kernel oil (FHPKO), FHPKO with 2.5% addition of hydrogenated palm oil (HPO) as nucleator, or fractionated palm kernel oil (FPKO).

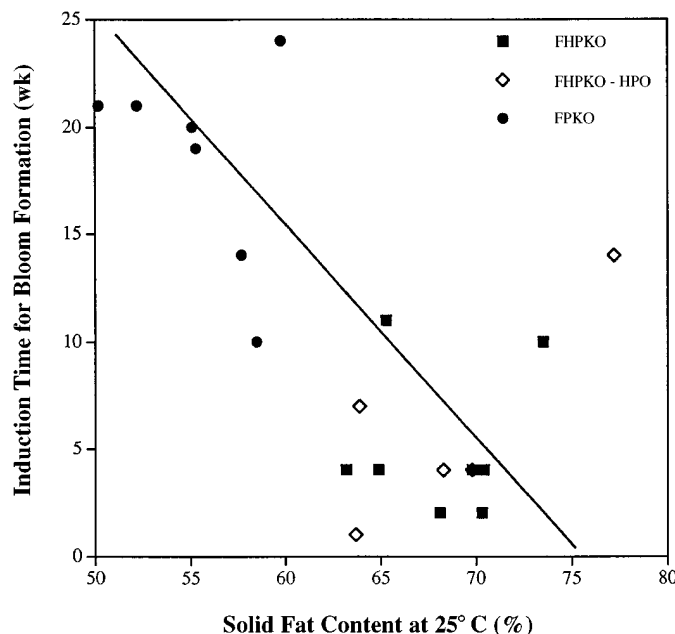


Figure 8. Comparison of induction time for bloom formation in compound coatings during storage at ambient conditions and solid fat content at 25°C of a binary mixture of the same composition of fats. Data points show various mixtures of milk fats or milk fat fractions with fractionated, hydrogenated palm kernel oil (FHPKO), FHPKO with 2.5% addition of hydrogenated palm oil (HPO) as nucleator, or fractionated palm kernel oil (FPKO).

faster than the control, except those made with 5% SAMF and 10% 17S. Coatings made with 17S had substantially lower bloom rates than did coatings made with the other milk fat fractions at all replacement levels. As melting point of the milk fat fraction increased, the rate of bloom formation increased. Also, as replacement level increased, the rate of bloom increased for these coatings.

The SFC at 25°C (hardness) for binary mixtures was correlated to bloom formation in compound coatings (Figures 8 and 9). Despite the low correlation coefficient, as hardness increased in a binary mixture, induction time for bloom formation for compound coatings with the same fat composition decreased. In Figure 9, the time required to reach full bloom decreased slightly as SFC at 25°C increased, although no significant differences were observed. These results indicated that harder compound coatings (higher SFC at 25°C) bloomed more rapidly than softer coatings. In addition, compound coatings containing higher melting milk fat fractions bloomed faster than those containing lower melting milk fat fractions because coatings made with higher melting milk fat fractions were typically harder.

This finding, that harder compound coatings are more prone to bloom, contradicts the trends in rates

of bloom in chocolate; harder chocolates are generally more resistant to bloom (19). Apparently, the mechanisms of bloom formation in compound coatings are different from those in chocolate. It is thought that a polymorphic transition is responsible for bloom formation in chocolate (22, 25), which cannot be the case in these compound coatings because x-ray spectroscopy showed that all of the coatings made here remained in the β' polymorphic structure throughout the duration of these experiments.

Other factors must be responsible for bloom formation in compound coatings made with PKO and milk fat or milk fat fractions. For example, addition of milk fat or milk fat fractions may have inhibited crystallization of PKO, as suggested by preliminary data of Williams (26). Because the cooling times and profiles were the same for all coatings, regardless of fat composition, differences in the kinetics of crystallization would have resulted in differences in crystalline structure within each coating (13). These differences might also affect bloom formation and should be studied more closely in future work.

One interesting anomaly in these results (Table 5 and 6) is that WAMF had much less of an effect than did SAMF in promoting bloom formation in these coatings. In the coatings that contained WAMF, bloom rates were comparable with those of the control coatings that were made with only PKO. Because the milk fat fractions were produced by fractionation of the SAMF, we were unable to isolate a component of SAMF that imparted bloom resistance that was equivalent to that with WAMF in these coatings. Perhaps fractionation of the WAMF might produce a fraction capable of inhibiting bloom formation in these coatings. These differences between SAMF and WAMF may be due to subtle differences in triglyceride structure or to differences in minor lipid (e.g., mono- and diglycerides) components.

CONCLUSIONS

Fractionated milk fat has previously been found to prevent fat bloom in chocolate. However, milk fat fractions appear to have limited compatibility when used in compound coatings made with PKO. Incorporation of lower melting milk fat fractions into these coatings produced softer products than the control coating. Coatings made with higher melting fractions, which did not exhibit substantial softening, exhibited increased rate of fat bloom development. A slower bloom rate was found in compound coatings made with addition of WAMF compared with those made with addition of SAMF. Differences in composition between WAMF and SAMF and their effects on bloom formation should be further investigated.

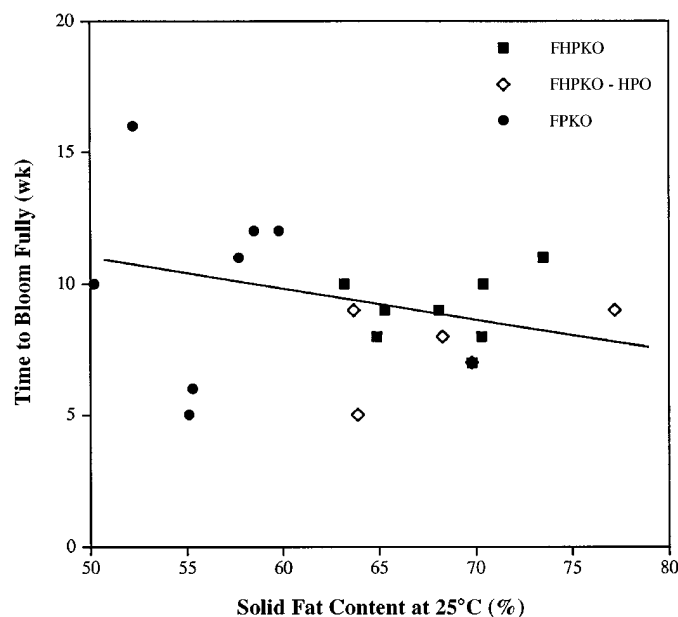


Figure 9. Comparison of rate of bloom formation in compound coatings during storage at ambient conditions and solid fat contents at 25°C of a binary mixture of the same composition of fats. Data points show various mixtures of milk fats or milk fat fractions with fractionated, hydrogenated palm kernel oil (FHPKO), FHPKO with 2.5% addition of hydrogenated palm oil (HPO) as nucleator, or fractionated palm kernel oil (FPKO).

ACKNOWLEDGMENTS

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