J. Dairy Sci. 87:20–31

Effects of Milk Powders in Milk Chocolate

B. Liang and R. W. Hartel
Department of Food Science,
University of Wisconsin,
1605 Linden Drive, Madison 53706

ABSTRACT

The physical characteristics of milk powders used in chocolate can have significant impact on the processing conditions needed to make that chocolate and the physical and organoleptic properties of the finished product. Four milk powders with different particle characteristics (size, shape, density) and "free" milk fat levels (easily extracted with organic solvent) were evaluated for their effect on the processing conditions and characteristics of chocolates in which they were used. Many aspects of chocolate manufacture and storage (tempering conditions, melt rheology, hardness, bloom stability) were dependent on the level of free milk fat in the milk powder. However, particle characteristics of the milk powder also influenced the physical and sensory properties of the final products.

(**Key words:** milk powder, chocolate, milk fat, rheological property)

Abbreviation key: AMF = anhydrous milk fat, **HFW** = powder made by drying cream and skim milk powder together, **LSN** = low-heat, spray-dried skim (nonfat) milk powder, **LSW** = low-heat, spray-dried whole milk powder, **RDW** = roller-dried whole milk powder, **SMP** = skim milk powder, **WMP** = whole milk powder.

INTRODUCTION

Over the years, a number of different types of milk powders have been explored for use in chocolates (Haylock, 1995). These include roller-dried and spray-dried whole milk powders (**WMP**), high-fat powders, buttermilk powders, whey powders, and skim milk powder sprayed with anhydrous milk fat (**AMF**) or cream. The characteristics of these powders are quite different, although they may have similar composition. Characteristics of milk powders of specific importance to milk chocolate manufacture include degree of free fat, particle size and structure, and air inclusion (Twomey and Keogh, 1998). Powders that contain high free fat, or fat that is easily extractable and can interact directly with the cocoa butter in chocolate, typically have been desired by milk chocolate manufacturers (Hansen and Hansen, 1990). The high free fat level results in reduced chocolate viscosity, making it easier to process the chocolate and providing an economy in cocoa butter savings (cocoa butter is usually added to control viscosity).

Numerous factors, not just free fat level, affect the properties of chocolates made with milk powder addition. Table 1 summarizes the properties of milk powders that can potentially influence chocolate characteristics. Characteristics such as particle size and density, internal structure, color, and flavor all potentially can influence the processing conditions needed to make chocolate, the physical properties of the chocolates produced, and/or the sensory characteristics of the final product.

For example, the size of particles in chocolate after refining (particle reduction) plays an important role in product viscosity. If particles are very small, viscosity is high, and additional fat is needed to coat these fine particles to reduce viscosity. Milk powders made of particles that break up easily into many small particles (as in some spray-dried powders) suffer from this problem. The strength of the particles, their shape, and the amount of air included in void spaces (vacuole volume) all impact the shattering aspects of powder particles and influence chocolate properties (fluid rheology and mechanical properties of the solidified product). Campbell and Pavlasek (1987) verified that powders with high vacuole (air) volume led to high chocolate viscosity, due to the effect of breakage into small particles that must be covered with fat. In spray-dried WMP, the use of centrifugal nozzles has been found to cause greater air incorporation than when pressure nozzles are used (Twomey and Keogh, 1998). Even nozzle size has been found to influence particle size and vacuole volume of milk powders (Twomey et al., 2001).

There are several factors that impact the degree of free fat in a milk powder, with the processing conditions being key to developing a powder with high free fat. Roller-dried WMP has a characteristically high free fat level (60 to 90%), apparently due to the shearing and scraping action as the film dries on a thin surface

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Received August 16, 2001.
Accepted July 24, 2003.

Corresponding author: R. W. Hartel; e-mail: hartel@calshp.cals.wisc.edu.

Table 1. Properties of milk powders and their influence on chocolate properties.

Properties of milk powder	Properties of chocolate or processing conditions
Particle size and distribution	Flow properties
Particle shape	Refining operations (particle size distribution)
Surface characteristics of particles	Tempering conditions (cocoa butter crystallization)
"Free" fat level	Hardness/snap
Particle density	Bloom stability
Flavor attributes	Flavor attributes

and then is removed by the knives. Because of this, roller-dried WMP is ideal for use in milk chocolate (Dewettinck et al., 1996). Spray-dried WMP has significantly lower free fat levels (only 2 to 3%), and it does not perform as well in milk chocolate (Campbell and Pavlasek, 1987). Chocolate manufacturers that use spray-dried WMP in their formulation typically use slightly higher concentrations of cocoa butter to keep viscosity down in the desired range. Thus, there is a strong economic incentive for chocolate manufacturers to use the optimal dairy ingredients for chocolate manufacture.

Processing parameters during spray drying can impact the level of free fat to some extent, although this has not been explored at great depth. Twomey and Keogh (1998) suggest that free fat in spray-dried WMP may be increased by using smaller nozzles and higher nozzle pressures. Hansen and Hansen (1990) saw an effect on chocolate viscosity between WMP atomized from a nozzle at different pressure. Higher nozzle pressure gave lower viscosity, most likely due to the higher free fat content. Lower drying capacities (temperature difference between product and air) also led to higher chocolate viscosity (Hansen and Hansen, 1990) in direct correlation to the measured free fat content (higher free fat with lower temperature difference). Another important factor that affects free fat levels is the degree of lactose crystallinity (Haylock, 1995; Twomey and Keogh, 1998), since the crystalline lactose (as opposed to amorphous lactose) causes the milk fat to be expressed from the droplet. Some manufacturers mimic a high free milk fat powder by blending AMF with skim milk powder (**SMP**). This provides 100% free fat to the chocolate but does not have the desired flavor characteristics (perhaps due to the lack of heating of the AMF). Thus, this alternative is not widely used (Campbell and Pavlasek, 1987).

The effects of free fat content in milk powder on milk chocolate rheology have been studied to some extent (Campbell and Pavlasek, 1987; Haylock, 1995; Twomey and Keogh, 1998). What is less clear are the effects of these powder properties on further processing requirements and the ultimate product characteristics of milk chocolate. The different structures produced in milk chocolates made with different milk powders potentially lead to differences in tempering requirements, different physical characteristics of the finished chocolate, and differences in stability to bloom formation. Finally, the flavor of milk chocolate also can be influenced by choice of powder ingredient.

Tempering of chocolate involves crystallization of the cocoa butter into the proper number of crystals of small size and desired polymorph. The temperature-time profile during tempering is regulated, depending on the nature of the chocolate, to produce this desired crystalline structure. The addition of milk fat is widely known to result in lower tempering temperatures due to the inhibitory effect on crystallization of cocoa butter (Hartel, 1998). Thus, powders with different free fat levels require different tempering conditions to attain the same degree of crystallization.

Hardness of chocolate is governed by a combination of the crystallized lipid phase and the solid dispersed phase (sugar crystals, cocoa solids, and milk solids). Addition of milk fat causes a softening effect on cocoa butter and results in softer chocolates. Thus, higher free fat levels from milk powder ingredients would be expected to lead to slightly softer chocolates. The packing arrangement of the dispersed phases in chocolate may also determine the mechanical properties of the solidified product (factors such as hardness, snap, etc.). Markov and Tscheuschner (1989) and Tscheuchner and Markov (1989) documented the effects of various additives on the physical properties of chocolate. Heathcock (1985) shows electron micrographs of different structures of chocolate based on type of milk powder used in the formulation.

The formation of fat bloom in chocolate is governed by many factors (Hartel, 1998), some of which are also influenced by choice of milk powder source. The amount of milk fat available from the powder source may influence the inhibition effect of milk fat on bloom formation since, in general, the higher the milk fat level, the greater the level of bloom inhibition (Hartel, 1996). A study by Bricknell and Hartel (1998) has shown that the shape and nature of the dispersed phase (sugar particles) influences the rate of bloom formation in chocolate. The packing arrangement of the particles and/or the surface shape/characteristics affect the rate of bloom formation. Thus, it is likely that choice of milk powder also influences the rate of bloom formation in milk chocolates, although no work has been done to verify this hypothesis.

The objective of this work was to evaluate the use of various milk powders in milk chocolate. The effects of different milk powders on processing condition requirements, physical properties, and sensory characteristics of the final milk chocolate products were studied. Chocolate properties evaluated include rheological properties of the chocolate melt, temperature conditions needed to produce well-tempered chocolate, hardness, bloom stability, and sensory properties.

MATERIALS AND METHODS

Milk Powders

Four different milk powders were obtained for this study. A low-heat, spray-dried skim milk powder (**LSN**) was obtained from Dairy America (Fresno, CA). A low-heat, spray-dried whole milk powder (**LSW**) was obtained from Foster Farms Dairy (Modesto, CA). A roller-dried, whole milk powder (**RDW**) was obtained from Vern Dale Products, Inc. (Detroit, MI). A high free fat milk powder produced by Parmalat, Canada, was supplied by Hershey Foods (Hershey, PA). This product was made by drying skim milk powder with cream.

Milk Powder Properties

Certain physical characteristics of milk powders influence the properties of the chocolate made from them.

Fat content. Total milk fat in each powder was determined by AOAC official method 932.06. Values ranged from 1.0% for LSN to 29.4% for RDW. The amount of fat easily extracted from a powder is often called "free" fat (Buma, 1971; Aguilar and Ziegler, 1994), since it is likely that this fat can interact with the matrix of the product to which that powder is applied. In this study, 2.5 g of milk powder was mixed with 40 ml of petroleum ether under gentle agitation for 1 h. After the extract was filtered, the solvent was evaporated and the amount of fat determined gravimetrically.

Lactose crystallinity. A Phillips PW 1729 x-ray diffractometer (Almelo, The Netherlands) was used to quantify the extent of lactose crystallization in each powder. Mixtures of pure α-lactose monohydrate and LSN (a completely amorphous powder) were used to generate a standard curve. A scan of 2θ between 15 and 30° with a step size of 0.05° and scan time of 10 s was used. A characteristic peak for lactose at 19.6° was used for reference purposes to estimate the percentage of lactose crystallinity in the milk powder samples based on the standard curve.

Density. Both apparent and true density of each milk powder were measured at room temperature. Apparent density (ρ_a) was measured by the volume displacement of sunflower oil. True density (ρ_t) was measured by using a pycnometer (AccuPyc 1330, Micromeritics Equipment Corp., Norcross, GA) with He gas at 236 kPa. Mean value and standard deviation of 10 measurements were calculated. The vacuole volume, or the void space within the powder particle, was calculated from the two densities as

$$\text{VacuoleVolume (ml/100 g)} = 100\left(\frac{1}{\rho_a} - \frac{1}{\rho_t}\right) \qquad [1]$$

Particle size and shape. Photomicrographs of each powder were taken with a Nikon Optiphot optical microscope (Garden City, NY) after dispersion of the powder in mineral oil. At least 10 randomly selected fields of view were used to accumulate over 800 particles for each distribution. Particle size distribution, based on the equivalent circular diameter of the projected area, was obtained by performing image analysis with Optimas 6.1 (Bothell, WA) software and a custom program for generating distribution statistics. Note that this measurement method gives a number-based size distribution, whereas light scattering devices generally give a volume-based distribution. Thus, mean sizes reported here are lower than those typically reported for chocolate particle size measured by light scattering.

The characteristics of each milk powder used in this study are shown in Table 2.

Chocolate Production

A standard milk chocolate (Minifie, 1989) formulation was used in this study. Milk chocolates (batch size of 1400 g) were made that contained 47% sucrose, 15.6% milk powder, 15% cocoa liquor, 22% cocoa butter, and 0.4% lecithin. The final chocolates contained 34.2% total fat of which 3.9% (on the chocolate basis) was milk fat. For the chocolate formulated with SMP (LSN), 3.9% AMF was added to the chocolate to bring the fat content in line with the other powders. Duplicate milk chocolates were made according to a standard protocol.

Refining. A laboratory-scale, three-roll refiner (model 4 × 8, Day, Cincinnati, OH) was used to reduce particle size of the mixture of sugar, cocoa liquor, cocoa butter (only about 2/3 of the total cocoa butter was added at this step), and milk powder. The roller gaps were set at 100 and 30 μm, respectively. Two passes through the refiner were used to ensure good particle size reduction.

Table 2. Characteristics of milk powders (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

Powder property	LSN	LSW	RDW	HFW
Milk fat in powder (%)	1.0 ± 0.1	28.8 ± 0.4	29.4 ± 0.4	26.7 ± 0.2
Milk fat in chocolate (%)[1]	4.02	4.49	4.59	4.17
Free milk fat in powder (%)	0.0 ± 0.1	1.6 ± 0.1	24.9 ± 0.2	20.4 ± 0.2
Free milk fat in chocolate (%)[1]	3.90	0.25	3.88	3.18
Total fat in chocolate (%)	34.3	34.7	34.8	34.4
Apparent density (g/cm^3)[2]	1.25 ± 0.03	1.13 ± 0.05	1.16 ± 0.03	1.12 ± 0.04
True density (g/cm^3)[3]	1.36 ± 0.01	1.24 ± 0.01	1.26 ± 0.01	1.26 ± 0.00
Vacuole volume (mL/100 g)[4]	6.69	7.31	6.54	10.56
Powder particle distribution:				
Mean size (μm)	24.0	48.2	104.7	55.8
Standard deviation (μm)	20.4	37.9	121.6	62.9
Coefficient of variation (%)[5]	84.9	78.6	116.1	112.7
Lactose crystallinity (%)	0.0	2.3	0.5	2.5

[1] % of fat on chocolate basis.

[2] Found by liquid volume displacement.

[3] Found by gas displacement.

[4] Found by difference from apparent and true densities.

[5] Variance of distribution divided by mean size.

Conching. A modified Hobart mixer (A-120T, 8 L, Troy, OH) was used to conch each chocolate. A plastic scraping blade was attached to the Hobart paddle mixer, and a heating mantle was placed around the Hobart bowl. The remainder of the cocoa butter and one-half of the lecithin were added at the beginning of the conch (60°C for 24 h). The remainder of the lecithin was added after about 6 h of conching.

Tempering and molding. A cyclothermic tempering procedure (Kleinert, 1970) was used to temper the chocolates. This process involves two sequential cooling and heating steps to promote formation of stable cocoa butter crystals. The best temperature conditions for attaining a tempered chocolate must be determined to some extent by trial and error, although measurement of viscosity changes (torque on a stirrer at constant rpm) after each change in temperature takes some of the guesswork out of this procedure. The cyclothermic tempering procedure is useful for ensuring excellent chocolate temper even for chocolates with different tempering requirements. A custom-built temper meter was used to measure proper crystallization during tempering, based on the shapes of the cooling curves in the temper meter. Chocolates were poured into plastic molds (50 mm diameter and 5 mm depth) or aluminum molds (20 mm diameter and 40 mm height) for hardness measurements and cooled in a 5°C room with gentle air movement. Proper temper was further verified by the visual appearance of the solidified chocolate products. The chocolates had good glossy surface, were not bloomed or dulled, and had excellent snap upon breaking.

Chocolate Analysis

Several analytical tests were performed on the chocolates, including particle size, rheological properties, hardness, and bloom stability. In addition, a sensory study was done to assess the effect of these milk powders on milk chocolate characteristics.

Particle size. There are numerous methods for measuring particle size in chocolate. Probably the most accepted method is laser light scattering. However, no suitable light scattering unit was available to the researchers at the time of this study, so an optical microscope technique was adopted. Melted chocolate was dispersed in mineral oil to create a dilute suspension of particles (sugar crystals, cocoa powder, and milk powder particles). A drop of this dispersion was placed on a microscope slide and observed with the Nikon Optophot microscope used for characterizing the milk powders. A magnification of 200× was selected to give a compromise between detecting the smaller particles (minimum detectable size was estimated at 0.6 μm) and not missing larger ones. Because most particles in chocolate are between 0.5 and 50 μm, the vast majority of particles are visualized under these conditions. Multiple frames (about 10) of each chocolate dispersion were analyzed to ensure random sampling and to minimize loss of larger particles due to the small frame size at this magnification. Automated image analysis using Optimas 6.1 software and custom-written software was performed to determine the particle size distribution based on the equivalent circular diameter of the projected area of each particle. At least 800 particles were counted for each distribution, and the population-based mean size, $L_{1,0}$, was calculated along with the standard deviation of the distribution.

Melt rheology. Rheological properties of the chocolate mass at 40°C were characterized by use of a Brookfield DV-1 HATD viscometer (Stoughton, MA) with a small sample adapter (SC4-13R) and spindle (SC4-21), according to the international guidelines (Office International du Cocao et du Chocolat, 1973). The chocolate mass was stabilized for 10 min in the temperature-controlled cup and presheared at 20 RPM for 5 min prior to measurement. Ascending (0.5 to 100 rpm) and descending (100 to 0.5 rpm) tests were performed for each sample. Torque readings at each shear rate were recorded after 30 s of shearing for duplicate samples. The data were analyzed according to the modified Casson model of fluid rheology (Steiner, 1958)

$$(1 + a)\tau^{0.5} = 2\tau_c^{0.5} + (1 + a)\eta_c^{0.5}\gamma^{0.5}, \qquad [2]$$

where τ is shear stress (obtained from torque data) and γ is shear rate (obtained from rpm data). The two parameters used to fit the Casson model are τ_c, the Casson yield value, and η_c, the Casson plastic viscosity.

Hardness. The molded chocolates were analyzed for hardness by using a Texture Analyzer (model TA-XT2, Haslemere, England) at 20°C. Test samples were penetrated by a 2-mm stainless steel cylindrical probe at 0.2 mm/s to a depth of 5 mm. Maximum force for penetration was determined as well as the work required for penetration (area under the force curve).

Bloom stability. Chocolate discs were stored either in a temperature-controlled cabinet with temperatures cycling between 19 and 29°C every 6 h to accelerate bloom formation or at room temperature. A Hunter color meter (Color QUEST, Hunter Associates, Reston, VA) was used to measure whiteness of the unmolded side of the chocolate disc (Bricknell and Hartel, 1998). An average of 4 readings on each disc (after 90° turn) was taken, and 8 different discs were used for each chocolate sample. Mean whiteness values and standard deviation are reported. A rough visual score of relative bloom formation was also used to evaluate each sample. Bloom level for each disk at each storage condition was rated on a scale from 0 (no bloom) to 5 (severe bloom) by the experimenter.

Sensory analysis. A descriptive panel, conducted according to IFT protocols through the Sensory Laboratory in the Department of Food Science, was used to judge a variety of attributes of milk chocolates. An experienced panel (n = 35) rated each chocolate on a 7-point scale for 11 attributes. These included brown color intensity, rate of melt down, textural smoothness, chocolate flavor, rate of chocolate flavor release, milk flavor intensity, milk powder flavor intensity, butter flavor intensity, mouth coating sensation, off-flavor intensity, and overall acceptability. The ballots with coded values for the descriptive attributes from the panel session were subjected to analysis of variance by use of SAS (Cary, NC) statistical software package. For each sensory attribute, statistical analysis provided the mean scores for each sample, the *F*-value for all samples, and the least significant difference (LSD) for making sample comparisons. The LSD value computed for a 5% level of significance was used for comparison of the paired means.

RESULTS AND DISCUSSION

Properties of Milk Powders

Based on the different methods used to make milk powders, significant differences in powder characteristics were observed (Table 2). Optical microscope images of the powders are seen in Figure 1. The free fat content of each milk powder varied from 0% for the spray-dried skim milk powder to 24.9% for the roller-dried whole milk powder. Initially, each of the milk powders, with the exception of LSN, contained 28.5% milk fat. Thus, different amounts of milk fat were easily removed from the powders with petroleum ether. Interestingly, the powder made by drying cream and skim milk powder together (**HFW**) had lower free fat content than the RDW. When used in chocolates, the "free" milk fat content in the chocolate varied from 3.9% for LSN (anhydrous milk fat added) to 0.25% for the spray-dried whole milk powder. The chocolates made with RDW and LSN (with 3.9% AMF addition) had approximately the same "free" milk fat content in the final chocolates. The values of free milk fat in the chocolate are only calculated and do not necessarily represent the actual amount of milk fat available to mix with the cocoa butter in chocolate. During refining and conching, for example, breakdown of particles may result in release of additional fat that may interact with the cocoa butter in the finished chocolate. The numbers reported here simply represent free milk fat based on the amount of milk fat easily extracted from the powders.

Densities of the various milk powders also varied due to processing effects. The powder with highest density (both apparent and true density) was LSN. The presence of milk fat in the other powders reduced the overall density of these powders due to the lower density of milk fat than milk solids. Based on the differences between true and apparent densities, the HFW powder had the highest vacuole volume. The agglomerated nature of the HFW powder was responsible for the presence of internal voids that led to the high vacuole volume.

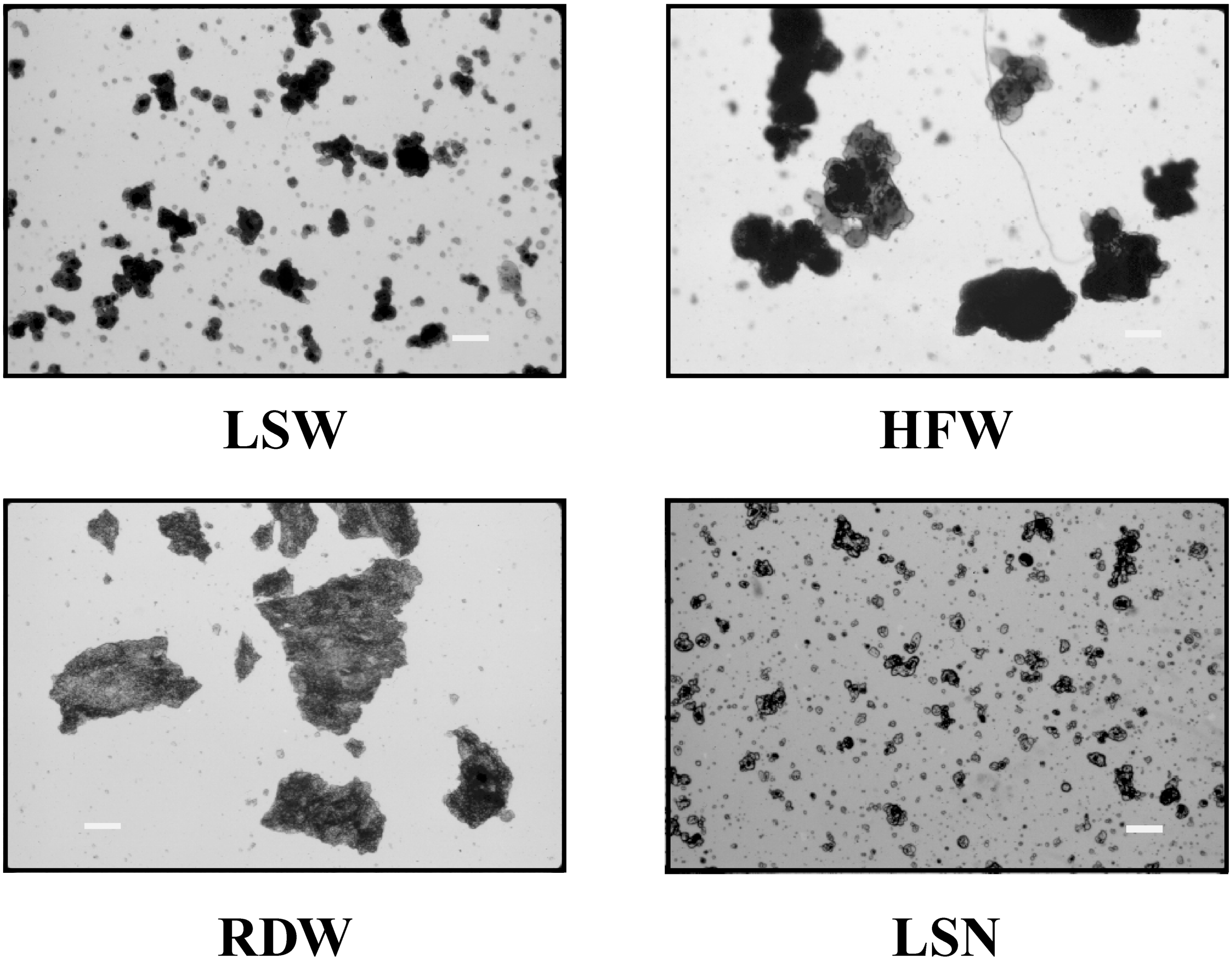

Figure 1. Optical micrographs of milk powders (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

Particle size distributions and shape of the particles in these milk powders also were different. The spray-dried skim milk powder had the smallest particles and narrowest distribution. The largest particle size, expressed as equivalent circular diameter for the projected area of each particle, was found in the roller-dried powder; however, the particles were flat, irregularly shaped, two-dimensional particles that were sized based on their largest area surface (Figure 1). This flat shape is likely to have different effects on the physical properties of chocolate, especially compared to the more uniform and spherical particles formed by spray drying. The powder made by drying cream and skim milk powder appeared as agglomerated particles of the original skim milk powder. Thus, the mean size of HFW was significantly higher than for the spray-dried powders.

Properties of Milk Chocolates

Particle size. The particle size of the chocolate impacts both the economic aspects of chocolate as well as the sensory aspects. The increased surface area that results from the formation of many small particles leads to higher costs since more cocoa butter must be added to reduce viscosity. Smaller particle size, however, generally leads to a smoother chocolate, unless particle size is reduced too much. Too many particles of very small size (less than 1 to 2 μm) can lead to a sensation of greasiness or slipperiness in the final chocolate. Thus, fragmentation of the particles into fines during refining can lead to increased cost as well as to an undesirable sensory attribute.

The different physical aspects of the milk powders may lead to differences in fragmentation during refin-

Table 3. Particle size statistics of chocolates made with different milk powders. (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

Powder property	LSN	LSW	RDW	HFW
Chocolate particle distribution:				
Count	888	1001	1001	881
Minimum (μm)	0.56	0.56	0.56	0.56
Maximum (μm)	21.0	37.2	46.3	16.4
Mean (μm)	2.8	3.1	3.3	2.7
Standard deviation (μm)	2.2	2.7	2.8	2.0
Coefficient of variation (%)[1]	78.2	88.7	84.8	71.2

[1] Variance of distribution divided by mean size.

ing. For example, a powder with higher vacuole volume may break into many smaller pieces than a more solid particle. An unusual shape, like the flat plates of the roller-dried sample, may also influence fragmentation during refining. Table 3 shows the particle size distribution statistics for each of the chocolates. In general, the size distributions of all chocolates were not dissimilar despite the differences in milk powder characteristics. This should not be surprising since the milk powder makes up only a small portion of the dispersed phase volume (along with sucrose and cocoa powder) and thus, does not have such a major effect on particle size distribution in the chocolate. One point of difference among the chocolates, however, is the relatively large size of the largest particles (up to 46 μm) in the chocolate made with the RDW. The particles of RDW were flat and large (Figure 1) and could easily slip through the roller gaps sideways without being fully broken down.

Melt rheology. The yield value (τ_c) represents the interactions among components of the fluid that impede motion when the fluid is at rest. Once the fluid is moving, the forces among the components of the fluid under shear conditions give rise to a viscosity value (η_c). Because chocolate has a dispersion with a high dispersed phase volume (55 to 65%), the particulate nature of a chocolate can have significant impact on the rheological properties. The size distribution of particles influences how easily they move across one another during shearing, as can the shape and surface characteristics. A decrease in mean size generally results in an increase in both plastic viscosity and yield value, as shown by Chevalley (1988). In addition, the dispersed phase volume itself is an important parameter that influences chocolate rheology. The presence of free fat (fat that is allowed to interact with the cocoa butter) in the milk powder, acts to effectively dilute the dispersed phase volume, leading to a reduction in both yield stress and plastic viscosity (Chevalley, 1988).

In this study, both Casson yield stress and plastic viscosity were influenced by the nature of the milk powders used to make the chocolates. Both yield stress and plastic viscosity decreased as the free fat in each powder increased (Figure 2). The chocolates with the lowest yield value and plastic viscosity were those that had the highest free fat level. In the case of LSN, 3.9% AMF was added to the formulation, which led to essentially all free milk fat for this chocolate. The chocolate made with the RDW had essentially the same level of free milk fat, based on the extraction method, which led to essentially the same yield stress and plastic viscosity. The chocolate made with LSW had essentially zero free milk fat, based on the negligible amount of milk fat easily extracted from the powder particles, and this chocolate had the highest yield value and plastic viscosity. A chocolate manufacturer would have to add additional cocoa butter to this chocolate to reduce viscosity to the desired specifications, a practice that would lead to higher costs.

Tempering conditions. Milk powder can potentially influence the tempering conditions needed during chocolate manufacture. The particles themselves may act as seed sites for nucleation of cocoa butter, so that the characteristics of the powder (size, distribution, surface properties, etc.) may influence temperatures

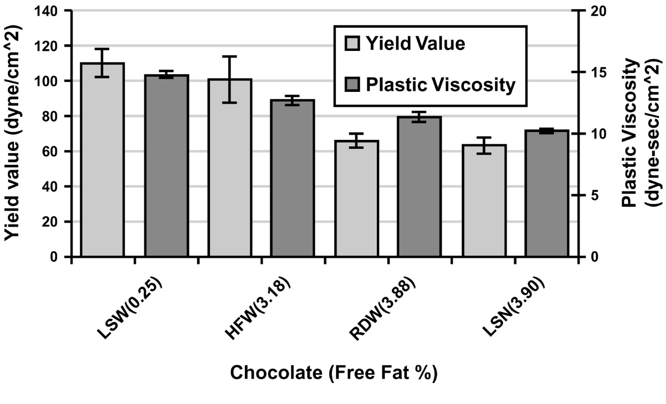

Figure 2. Effect of free fat level in milk powder on rheological properties of melted chocolate (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

Table 4. Tempering conditions required in the cyclothermic tempering profile to obtain proper temper of milk chocolates (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

Tempering condition[1]	LSN	LSW	RDW	HFW
T_1 (°C)	26.0	27.0	26.0	26.5
D_1 (min)	25	20	25	32
M_1 (mV)	95	107	87	92
T_2 (°C)	31.5	30.5	31.0	31.5
D_2 (min)	10	10	10	10
M_2 (mV)	67	85	60	65
T_3 (°C)	30.0	28.5	27.0	28.0
D_3 (min)	5	10	15	10
M_3 (mV)	102	102	77	97
T_4 (°C)	32.5	32.0	32.0	32.5
D_4 (min)	10	10	10	10
M_4 (mV)	70	80	60	72

[1] Cyclothermic tempering profile (T is temperature at each step, D is duration at each temperature, and M is final torque meter reading on stirrer at each temperature).

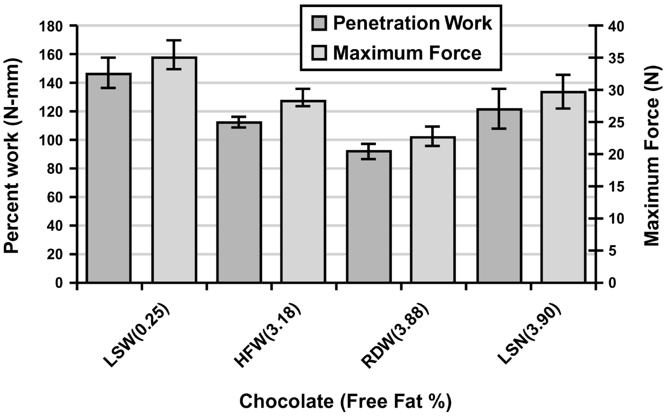

Figure 3. Hardness of chocolates made with different milk powders. (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

needed for proper tempering. Perhaps more important is the level of free milk fat in the powder, since it is widely known that milk fat influences cocoa butter crystallization (Metin and Hartel, 1996). Higher levels of milk fat in a chocolate formulation require lower temperatures to promote proper crystallization of the cocoa butter.

The approximate conditions needed for proper tempering of each chocolate (based on temper meter curves and visual observation of the finished chocolates) are shown in Table 4. Several trends among milk powders were observed, including the initial temperature for tempering and the torque required to maintain constant RPM during stirring. The chocolates with high free milk fat required slightly lower temperatures in the first step of tempering. The milk fat inhibited cocoa butter crystallization so lower temperatures were required in the first stage to promote the desired nucleation of cocoa butter. In addition, the chocolates made with roller-dried milk powder required lower torque (M) than the other chocolates to maintain constant RPM of the stirrer during tempering. Because torque is generally directly related to viscosity, it is surprising that the melt viscosity of this chocolate is not lower than the viscosity of the chocolate made with skim milk powder supplemented with AMF (LSN) with the same free fat level (Figure 2). However, as cocoa butter crystals form and interact with the solid particles, the rheological properties of the melt may change.

Hardness. Numerous factors influence hardness of molded chocolates, including the nature of the particulate dispersion and the nature of the crystalline fat system. Milk chocolates tend to be softer than dark chocolates primarily because the milk fat dilutes the cocoa butter, resulting in a lower solid fat content at any temperature. Thus, milk powders with different free milk fat content may be expected to have an influence on chocolate hardness. However, the nature of the dispersed phase particles and their interaction with the fat components may also influence the hardness of chocolate.

Figure 3 shows that an increase in free milk fat content in chocolate generally led to a decrease in hardness, as might be expected based on the dilution of cocoa butter mentioned above. This result was seen for both the maximum force of penetration as well as the total penetration work (area under the force curve). However, the chocolate made with the spray-dried skim milk powder supplemented with AMF (LSN) had higher hardness than expected based on free milk fat content. Apparently, the nature of the milk powder particles also influences the hardness of chocolate, although the exact mechanism for this effect is not clear.

Bloom stability. The addition of milk fat to chocolate retards the development of bloom in chocolate during storage (Lohman and Hartel, 1994; Bricknell and Hartel, 1998). It is thought that milk fat inhibits the polymorphic transformation of cocoa butter to the most stable state, although the exact mechanisms of bloom formation are not clearly understood. It has also been shown recently that the nature of the sugar dispersion influences development of visual bloom in chocolates (Bricknell and Hartel, 1998). Thus, it should be expected that milk powders with different characteristics would influence bloom stability in different ways.

Figure 4 shows the formation of bloom in milk chocolates, made with different milk powders, after storage for 9 wk with the temperature fluctuating from 19 to

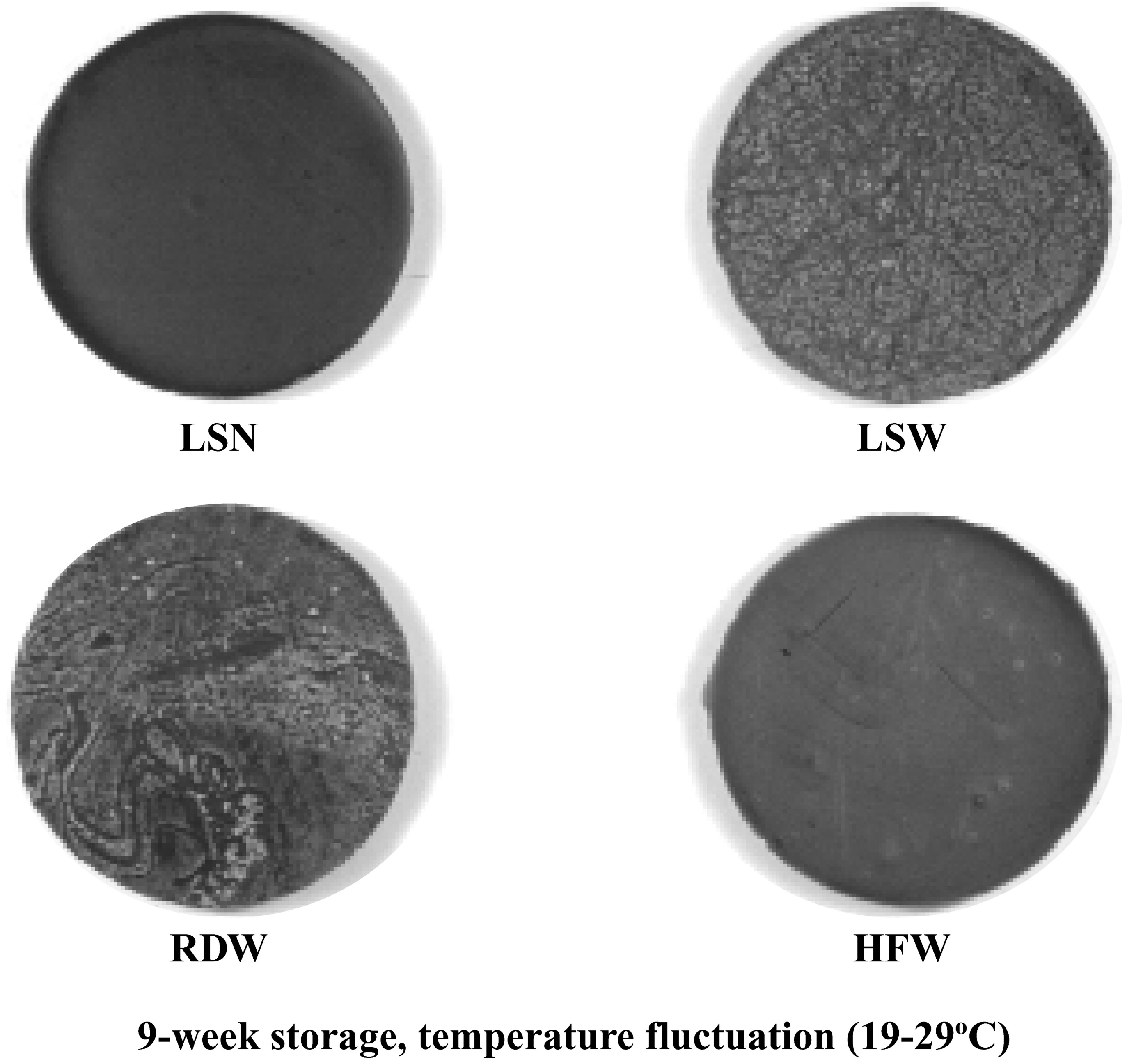

Figure 4. Bloom formation in milk chocolates made with different milk powders after storage for 9 wk with temperature fluctuating between 19 and 29°C every 6 h (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

29°C on a 6-h cycle. Figure 5 shows the results for visual observation of bloom formation under the same conditions. In both measurements, the chocolate made with LSN and supplemented with AMF was quite resistant to bloom formation, having essentially the same appearance (and little change in whiteness index; see Figure 6) as the original chocolates. The chocolate made with HFW also had good bloom stability, showing just dulling under these accelerated storage conditions. Although the whiteness index for the chocolate made with HFW increased after 3 wk of storage, after 9 wk it was back to a low value matching the visual observation. In contrast to these stable chocolates, the chocolates made with RDW and LSW had bloomed significantly (both in whiteness index and in visual evaluation) during this time period of storage.

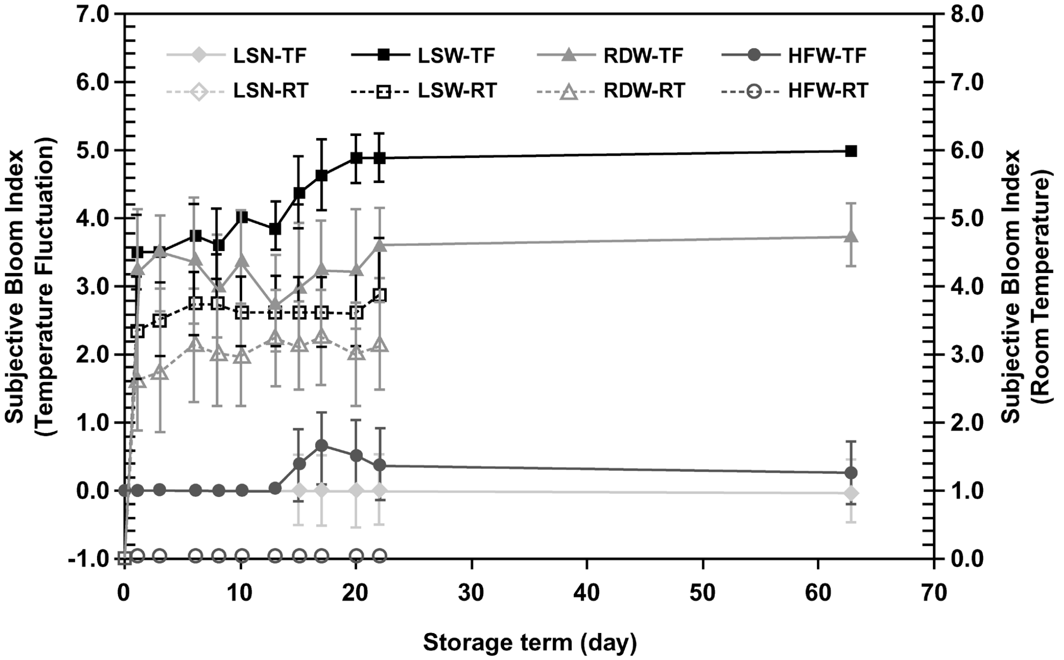

Figure 5. Bloom stability, as measured by whiteness index, of chocolates made with different milk powders and stored at conditions of room temperature (RT in legend) or fluctuating temperatures (TF in legend), with temperature changing from 19 to 29°C every 6 h. (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

Interestingly, these bloom stability results do not correlate exactly with the free milk fat levels in these chocolates. The chocolate made with RDW has essentially the same level of free milk fat as the chocolate made with LSN, yet one has bloomed and the other has not. Thus, the nature of the particulate dispersion must also play a role in the bloom stability of these chocolates. However, further work is needed to understand the effects of the particulate dispersion characteristics on bloom inhibition in chocolates. Figure 6 shows the development of bloom during storage of these chocolates at both cycling temperature conditions and room temperature. The chocolate made with LSN (with added AMF) had the least bloom under both storage conditions.

Sensory analysis. An experienced sensory panel was used to evaluate 11 characteristics of the milk chocolates made with different milk powders. Results of the sensory analysis are shown in Table 5. Only slight (but still statistically significant at $P < 0.5$) differences were observed among the chocolate samples based on the properties of the milk powders used. There was no clear correlation between free milk fat levels and brown color intensity, meltdown rate, milk flavor, and milk powder flavor. Chocolate flavor, chocolate flavor release, and mouth coating sensation also were not influenced significantly by the different milk powder types. It is likely that the level of milk powder used in this study was too low to clearly demonstrate the sensory differences expected from the different milk powders, even though this level was sufficient to observe differences in physical properties.

CONCLUSIONS

Numerous properties of milk powders influence the characteristics of milk chocolates made from those powders. Of these properties, the free milk fat available to mix with the cocoa butter in the chocolate and the particle characteristics are arguably the most important. The level of free milk fat influenced the tempering conditions needed to ensure proper crystallization of the cocoa butter in chocolate. The free milk fat level also had a significant influence on rheological properties, with lower viscosity and yield stress of the melted chocolate and generally reduced hardness of the finished chocolate as free milk fat increased. However, the chocolate made with the highest free milk fat was slightly harder than expected, probably as a result of the small dense particles that made up that powder. Bloom inhibition was generally related to free milk fat level, where

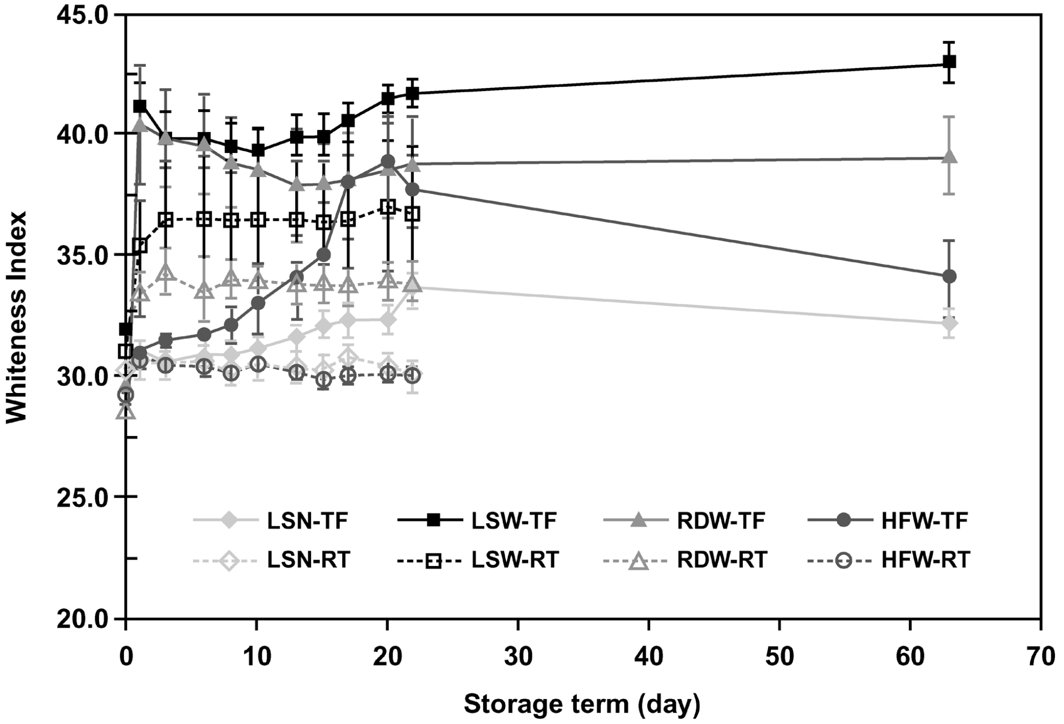

Figure 6. Bloom stability, as measured visually on a scale of 0 (no bloom) to 5 (severe bloom), of chocolates made with different milk powders and stored at conditions of room temperature (RT in legend) or fluctuating temperatures (TF in legend), with temperature changing from 19 to 29°C every 6 h. (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

chocolates made with higher free milk fat levels had greater bloom stability. However, the chocolate made with roller-dried milk powder was the exception. It had a high concentration of free milk fat but was still observed to bloom readily. This may be due to the effect of particle shape and characteristics. None of the measured sensory attributes correlated very well with free milk fat levels, suggesting that other factors were also important in consumer perception. Particle size correlated well with the sensory evaluation of smoothness. In summary, although both the level of free milk fat and the characteristics of the milk powder particles influenced chocolate properties, neither parameter alone could fully explain all the results.

Table 5. Sensory analysis (n = 35) of milk chocolates made with different milk powders. Scores were rated on a scale from 1 (least) to 7 (most) (LSN: spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: skim milk powder dried with cream in fluidized bed).

Attribute	LSW	HFW	RDW	LSN	LSD[1]
Brown color intensity	3.57^{C}	4.85^{A}	4.24^{B}	$4.42^{A,B}$	0.46
Rate of meltdown while chewing	4.84^{A}	3.39^{B}	4.51^{A}	3.55^{B}	0.53
Textural smoothness upon melting	$4.1^{A,B}$	3.74^{B}	3.69^{B}	4.39^{A}	0.63
Chocolate flavor intensity	4.49^{A}	3.83^{B}	3.84^{B}	3.91^{B}	0.50
Rate of chocolate flavor release	4.21^{A}	3.51^{B}	$3.99^{A,B}$	3.65^{B}	0.54
Milk flavor intensity	4.23^{A}	3.56^{B}	4.18^{A}	$3.98^{A,B}$	0.48
Milk powder flavor intensity	4.14^{A}	3.57^{B}	$3.97^{A,B}$	$3.86^{A,B}$	0.54
Butter flavor intensity	3.61^{A}	3.18^{A}	3.54^{A}	3.42^{A}	0.54
Overall mouth coating sensation	4.49^{A}	3.35^{B}	3.78^{B}	3.59^{B}	0.51
Off-flavor intensity	2.96^{A}	3.08^{A}	3.15^{A}	2.89^{A}	0.59
Overall acceptability	3.98^{A}	3.8^{A}	3.64^{A}	4.18^{A}	0.57

^{A,B,C,D}Values with different letters in a row are statistically different ($P < 0.05$).

[1] LSD—least significant difference.

ACKNOWLEDGMENTS

Funding provided by Dairy Management, Inc. through the Wisconsin Center for Dairy Research. The donations of Hershey Chocolates and Vern Dale Dairy are gratefully acknowledged.

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