The functionality of milk powder and its relationship to chocolate mass processing, in particular the effect of milk powder manufacturing and composition on the physical properties of chocolate masses

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Summary The functionality of twelve different milk powders that are used for chocolate mass processing was investigated. In two types of spray-dried and one type of roller-dried powder, the milk fat and milk fat fractions were integrated. Depending on the production process, the amount of free fat available in the milk powders varied greatly. A good correlation was found between the free fat content of the milk powder and the viscosity of the chocolate mass when comparable particle sizes were used. This study reports on the development of spray-dried milk powders, which when used in chocolate processing produced low viscosities, comparable with those obtained by using roller-dried milk powder. Calorimetric analysis showed that the shape of the milk powder particles has no influence on the calorimetric qualities of chocolate masses. Only when milk fat was added in a free form, was a higher ‘mixing effect’ in the crystallization peak of cocoa butter and milk fat observed.

Keywords Chocolate processing, milk fat fractions, modified milk powder, rheology, roller-dried/spray-dried milk powder.

Introduction

Useful applications of milk fat in food and non-food systems are increased when its physical and chemical properties are modified. Examples of those properties that can be modified are: crystallization and melting behaviour and surface-active and nutritional properties. A detailed overview of modification methods, such as fractionation, texturization and interesterification, has been published (Kaylegian, 1995). Depending on the context of the process, specific combinations of methods have been developed to tailor products to meet the needs of the consumer and manufacturer.

Milk fat is commonly used in chocolate because of its desirable flavour and its lower price compared with cocoa butter. Adding milk fat also influences the physical properties of chocolate masses, such as the crystallization behaviour of cocoa butter and the texture of the final chocolate. A negative correlation between the amount of milk fat used and the hardness of chocolate has been reported. Although this softening effect of milk fat in chocolate limits its use, up to 30% of cocoa butter can be replaced by milk fat before the product gets unacceptable (Hartel, 1996).

Low-melting, middle-melting or high-melting fractions of milk fat can be isolated by fractionation, these fat fractions have enhanced properties in processing. Several authors have investigated the use of milk fat fractions in chocolate. An improved stability of chocolate bloom can be obtained using high-melting milk fat fractions. As different milk fat fractions have different characteristics, modifications in the processing conditions of chocolate
are required, depending on the fraction used. Investigations on the crystallization and tempering properties of chocolate masses have been reported by Dimick et al. (1996), Hartel (1996), Reddy et al. (1996) and Ziegler (1985).

Flow properties of chocolate masses are a very important quality aspect. Low viscosities of the masses are absolutely required for chocolate manufacturing, as they enhance the moulding process. As this process is applied at temperatures around 30 °C, not only the total fat content, but also the solid fat content (fat crystal content) in the chocolate mass, at these temperatures, plays an important role in its flow behaviour. Although use of cocoa butter will lower the viscosity of the chocolate mass, it is one of the most expensive components in the chocolate industry. Therefore, other components have been investigated to decrease chocolate mass viscosity during production.

Some investigations on the flow behaviour of milk chocolate, using milk powders produced by different technologies, have been reported by Dewettinck et al. (1996). The authors reported that roller-dried milk powder could not be replaced by spray-dried milk powder because of the insufficient flow properties of the latter material. The useful flow properties of roller-dried milk powder have been correlated with its high content of free fat [the method is described in A/S Niro Atomizer: In Analytical Methods for Dry Milk Products. De Forenede Trykkerier, Copenhagen (1978)] as compared with spray-dried milk powder, although other factors, such as the inner structure of milk powder particles, are assumed to play an important role in controlling the flow characteristics of chocolate mass. Use of spray-dried skimmed milk powder combined with milk fat was reported as an interesting solution to maintain the desired flow properties.

So far very few papers have focussed on the viscosity of chocolate masses containing different milk fat fractions. It has been reported that there is no significant change in viscosity, compared with controls, when conched chocolate samples are prepared at 40 °C containing skimmed milk powder and milk fat fractions in a free form up to 40% of the total fat (Dimick et al., 1996). Reddy et al. (1996) noted differences in chocolate mass viscosity during tempering when high-melting milk fat fractions partly replaced cocoa butter (20–35% of the total weight of fat), the resultant mixtures were too viscous under normal tempering conditions to deposit easily into the moulds. Therefore, chocolate masses containing high-melting fractions required slightly higher crystallization temperatures.

The aim of this work was to investigate how milk powders affect the flow behaviour of the chocolate mass. The influence of milk powder types (prepared from different production technologies and from incorporation of different milk fat fractions) on physical properties of chocolate masses is reported. To do this twelve different milk powders from Säntis Milchpulver AG (Sulgen, Switzerland) were used for chocolate mass manufacturing on a pilot scale. Rheological, calorimetric and microstructural analysis, such as light microscopy, scanning electron microscopy (SEM) and particle size determinations, were used to characterize the raw materials and intermediate products as well as the final chocolate masses. Textural properties, bloom-stability and sensory analysis of the final chocolates depended on the tempering procedure and were not part of this study.

Materials and method

Formulation and production of chocolate masses

Ten different whole milk powders [fat content 25.3–28% (all declarations given in percentage are related to weight)] and two skimmed milk powders (fat content 0.5%) were used to produce chocolate masses. The final target fat content of the chocolate masses was 31.5%. Milk fat content of the masses varied between 6.57 and 7.55% of the total fat weight. The variation in milk fat amount was adjusted using sugar and cocoa butter in order to maintain the same total sample weight.

The milk powders used were two types of spray-dried (SP type A and B) and one type of roller-dried (RP) milk powder and were produced by Säntis Milchpulver AG. In order to manufacture type A milk powder various milk fat fractions were homogeneously mixed into the skimmed milk prior to drying. In contrast to this method, production of type B spray-dried powder made use of a different technology. To achieve a high level of free fat,
various milk fat fractions were sprayed on to dried milk powder drops. For SP-A(GOLD)-AMF a combination of both technologies A and B were used. Into each of the three milk powder types conventional milk fat (AMF, melting point 35 °C), high- (HMF, melting point 41 °C) or low- (LMF, melting point 18 °C) melting milk fat fractions were incorporated at 26.4 ± 0.8%. Owing to the different technologies used, the free fat content of the milk powders varied between 3.7 and 97.4%. Furthermore, roller- and spray-dried skimmed milk powders were also used and a middle melting milk fat fraction (MMF, melting point 26 °C) was added separately to the other ingredients before refining. An overview of the milk powders used, their fat and free fat contents, as well as the fat content of the flakes (mass after refining), are listed in Table 1. Additionally the commercial names of the milk powders used are given.

For each batch 350 g of mass were produced. The final chocolate masses were composed of the following ingredients: 13% cocoa liquor (55% fat – from Ivory Coast), 26% whole milk powder (whole milk powder containing 25.3–28% fat, Säntis Milchpulver AG) or 19.2% skimmed milk powder (0.5% fat to which 6.8% MMF were added to obtain 26% in total, Säntis Milchpulver AG, Sulgen, Switzerland), 0.56% lecithin (Topicithin liquid, 38% fat – Sargo AG, Basel, Switzerland), 42.8–43.5% sugar (sucrose; Südzucker AG, Mannheim, Germany) and 16.8–17.5% cocoa butter (West Africa).

Refining
Sugar, cocoa liquor, milk powder and part of the cocoa butter were mixed in a laboratory mixer (Type UM 60 EV2; Robert Bosch Hausgeräte GmbH, Munich, Germany) for 1 min. The total fat content of this mixture was adjusted, depending on the free fat content of the milk powder used, so as to obtain a particular consistency of the mass before refining, this varied between 21 and 29% (Table 1). The consistency of this mixture was an important factor in the refining process and influenced the particle size distribution of the flakes. No lecithin was added prior to conching.

The mass was refined in two passes through a horizontal three-roll refiner (Type 69907, Bühler AG, Uzwil, Switzerland). The median particle diameter (volume based) of the obtained chocolate flakes was 10.1 ± 1.4 μm.

Conching
The chocolate flakes were conched with a laboratory kneader (Type 811201OHG, Brabender® Technologie KG, Duisburg, Germany) with a tempered jacket. The flakes were mixed for

Table 1 Overview of milk powders used, their commercial names, abbreviations, fat content, free fat content (Säntis Milchpulver AG, Sulgen, Switzerland) and fat content of mass prior to refining

<table>
<thead>
<tr>
<th>Milk powders</th>
<th>Commercial names</th>
<th>Abbreviation</th>
<th>Fat content (wt %)</th>
<th>Free fat content (wt %)</th>
<th>Fat content prior to refining (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spray-dried (SP type A)</td>
<td>Sulgaspray S 26</td>
<td>SP-A-AMF</td>
<td>26.5</td>
<td>3.7</td>
<td>27</td>
</tr>
<tr>
<td>Sprayspray Gold S 26</td>
<td>*</td>
<td>SP-A(GOLD)-AMF</td>
<td>25.8</td>
<td>91.9</td>
<td>24</td>
</tr>
<tr>
<td>Sprühmager Milchpulver</td>
<td>*</td>
<td>SP-A-HMF</td>
<td>27.5</td>
<td>3.9</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>SP-A-LMF</td>
<td>28.0</td>
<td>11.6</td>
<td>27</td>
</tr>
<tr>
<td>Roller-dried (RP)</td>
<td>Sulgachoc S 26</td>
<td>SP-skimmed</td>
<td>0.5</td>
<td>99.5†</td>
<td>25</td>
</tr>
<tr>
<td>*</td>
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<tr>
<td></td>
<td>Sprühmager Milchpulver</td>
<td>SP-skimmed</td>
<td>0.5</td>
<td>99.5†</td>
<td>25</td>
</tr>
</tbody>
</table>

AMF, Anhydrous milk fat; MMF, Middle-melting fraction (melting point 26 °C); HMF, High-melting fraction (melting point 41 °C); LMF, Low-melting fraction (melting point 18 °C); wt %, Weight percentage; *Commercially not available; †MMF added.
15 min in a dry state at 25 °C and 60 r.p.m. to ensure aeration. No special appliances were used for aeration, but the cover of the conche was left open to allow exchange of air. The relative humidity of the air was, on average, 30%. Subsequently, the temperature of the tempering jacket was increased to 80 °C. As soon as the temperature of the chocolate flakes reached 45 °C (usually between 40 and 45 min), which ensured melting of the high-melting fat fractions, cocoa butter was added bit by bit up to a maximum fat content of 31%. The aim was to achieve a pasty consistency of this mass; this depended on the free fat content and the microstructure of the milk powder used. This consistency was maintained for 60 min at 60 r.p.m. Then 0.56% lecithin was mixed with the remaining cocoa butter and added to the mass to obtain a final total fat content of 31.5% in all chocolate masses. After an additional 15 min at 60 r.p.m., the heating of the tempering tool was switched off and the mass was conched at 120 r.p.m. for 15 min until a homogenous chocolate mass was obtained.

The samples were filled into 500 mL plastic containers, closed and stored at 5 °C until further analysis and measurements were performed. All samples were produced in duplicate.

Analysis

The chocolate masses were melted during 4 h at 50 °C in a tempered oven before further analysis. All measurements described subsequently were duplicated.

Particle size distribution

Five teaspoons of chocolate flakes were mixed with some drops of sunflower oil (Florin; Florin AG, Muttenz, Switzerland) in a mortar. This mixing was performed gently so as not to destroy any primary particles. Approximately 200 mg of this mixture were filled into a test-tube together with 20 mL of sunflower oil (Florin; Florin AG) and treated in an ultrasonic bath (Type T480/H-2, Transsonic Digital; Elma GmbH, Singen, Germany) for 20 min at 30 °C to destroy agglomerates. The particle size distribution of the resulting homogenous suspension was measured by laser diffraction spectroscopy (Multi Sync 3FG; Malvern Instruments Ltd, Worcs, UK). A lens with a focal length of 300 mm and software using the standard Fraunhofer diffraction model was used. Particle size was measured after roll refining, it can be assumed that particle shapes for both types of milk powders were changed, because of the fraction used, during the refining process. Therefore any model, such as the Fraunhofer, will give only approximate results. Laser diffraction is widely used as a tool for particle size analysis and its limits in terms of shape are generally known and accepted.

In order to measure particle size of the chocolate mass, about 200 mg of chocolate mass were directly inserted into test-tubes together with 20 mL sunflower oil, sonicated for 20 min and measured with the same arrangement as was used for flakes.

Rheology

The viscosity of the chocolate masses was determined in a controlled, stress viscometer [Dynamic Stress Rheometer (DSR); Rheometric Scientific GmbH, Bensheim, Germany] using a coaxial cylinder system (Searl type, diameter of cup 29.6 mm, gap width 1.15 mm).

To remove air bubbles, approximately 17 g of chocolate mass were filled into the cup and shaken on a Vortex (Heidolph REAX 2000; Heidolph Elektro GmbH, Kelheim, Germany) for 5 min. The cup was then fixed into the viscometer and remained undisturbed until the temperature was stabilized at 45 °C. Pre-shearing was performed at 150 Pa for 180 s. Then the shear stress was increased from 0.5 to 289 Pa and thereafter decreased from 289 to 0.5 Pa in nineteen steps, with a delay time of 60 s before each measurement. On the basis of the measured rotational speed both shear rate and viscosity are calculated. Following the regulations of the International Office of Cocoa, Chocolate and Sugar Confectionery (IOCCC, 1996) viscosities at shear rates 2, 5, 10, 20 and 50 s⁻¹ were interpolated linearly from the calculated data.
Differential scanning calorimetry (DSC)

The crystallization behaviour of the chocolate masses was measured in a differential scanning calorimeter (Type DSC Gold +; Rheometric Scientific GmbH, Bensheim, Germany). Approximately 10 mg of chocolate mass were transferred into an aluminium pan and closed. To melt all existing crystals the temperature was kept at 50 °C for 5 min before starting a cooling ramp at 4 °C min⁻¹ from 50 to 0 °C. The temperature was then kept at 0 °C for 10 min to ensure complete solidification. Afterwards, the resulting crystals were melted at a heating rate of 4 °C min⁻¹ from 0 to 50 °C. During cooling and heating, the exothermic and endothermic heat flow resulting from crystallization and melting, respectively, were registered. Each chocolate mass was measured in duplicate using the method described above.

Chemical analysis

For all the chocolate masses produced the total fat content, using the Soxhlet method (IOCCC, 1988) and moisture content, using the Karl–Fischer method (IOCCC, 1990), were determined. The content of free fat in all the milk powders had been determined by the original producer.

Microscopy

Light microscopy (Inverse-microscope Nikon DIAPHOT TMD; Nikon AG, Küsnacht, Switzerland) was used for qualitative control of deagglomeration of chocolate flakes during conching. This was important as the desired pasty consistency during conching was not obtained for all chocolate masses. Therefore, chocolate mass was carefully diluted in sunflower oil down to a concentration of 0.1% (wt).

Scanning electronic microscopy was used to get information about shape and inner structure of the different milk powders. Together with a drop of Glycerol (Flucka Chemie AG, Buchs, Switzerland) milk powder was placed on a sample holder and quickly frozen in liquid nitrogen, transferred in a freeze fracturing device (BAF 300; Balzer AG, Balzers, Liechtenstein) and broken at −100 °C, etched for 5 min, followed by shadowing with 2.5 nm platinum and 6 nm carbon at an angle of 45°, cryo-transferred into the SEM (Hitachi S 900; Prophysics AG, Uster, Switzerland) and SE-imaged at −100 °C.

Results and discussion

Detailed information (X₁₀, X₅₀ and X₉₀) on the particle size distribution of all chocolate flakes and conched masses, produced with different milk powders, in these experiments is given in Table 2. For every batch produced, particle sizes were determined twice and, as each chocolate mass was produced in duplicate, the average of four values was considered as the resulting particle size for each chocolate mass type (each containing a certain type of milk powder). The data given in Table 2 are averaged (and their s.d.) for all data points for X₁₀, X₅₀ and X₉₀. The large shift between the X₉₀ of flakes and conched chocolate masses resulted from an insufficient energy input during sample preparation in the ultrasonic bath. This treatment was used for destroying agglomerates, which had been generated during the refining process. Conching alone led to the destruction of most of these agglomerates. Very low s.d. were found in samples for the particle sizes X₁₀ and X₅₀ for both flakes and chocolate masses. The s.d. for the particle size X₉₀, for both flakes and chocolate masses, was relatively high at 20%. In Table 2 number and volume related particle sizes for the chocolate masses are listed. Compared with volume related particle sizes the s.d. related to the numbers for X₉₀ was reduced to 3.7%. This huge reduction in particle size and s.d. resulted because, in the volume related characteristics, very few large particles have an enormous effect on the particle size distribution, shifting them to larger particle diameters. The low s.d. in the number-related distributions and the similarity of the

<table>
<thead>
<tr>
<th></th>
<th>X₁₀ (s.d.) (µm)</th>
<th>X₅₀ (s.d.) (µm)</th>
<th>X₉₀ (s.d.) (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flakes*</td>
<td>3.07 (0.25)</td>
<td>10.07 (1.43)</td>
<td>26.23 (5.45)</td>
</tr>
<tr>
<td>Chocolate*</td>
<td>2.57 (0.12)</td>
<td>7.38 (0.75)</td>
<td>21.06 (4.14)</td>
</tr>
<tr>
<td>Chocolate†</td>
<td>1.35 (0.05)</td>
<td>1.95 (0.07)</td>
<td>3.90 (0.14)</td>
</tr>
</tbody>
</table>

*volume-based; †number-based.
monomodal shapes of particle size distribution maps in all the chocolate masses show the uniformity of the production method. This led to the conclusion that rheological differences of the chocolate masses were not caused by any differences in their particle size distributions.

The average fat content of the chocolate masses was measured as 30.9 ± 0.5%, therefore variations in fat content and thus its effect on flow behaviour can be excluded. The moisture content of the chocolate masses at the time of the rheological measurements was, on average, 0.8 ± 0.2%. The s.d. in the moisture content of more than 25% was traced back to the different milk powders used and their storage time.

Figure 1 compares representative viscosity curves of the different chocolate masses measured at 45 °C. In this figure, the viscosity curves measured with decreasing shear stress (289–0.5 Pa) are shown. Only viscosities above 1 s⁻¹ should be taken into account because, at shear rates lower than 1 s⁻¹, wall slip effects cannot be neglected.

Two different groups of chocolate masses can be distinguished in Fig. 1. The first, higher viscosity group, contains spray-dried milk powders of type A with high-melting (SP-A-HMF), and low-melting (SP-A-LMF) milk fat fractions as well as anhydrous milk fat (SP-A-AMF). In contrast to all other milk powders used, these have a very low free fat content in common (Table 1). Refining masses containing these milk powders was difficult, particularly the process to obtain the desired particle size distribution. During the conching process the pasty consistency of these masses could not be reached before lecithin was added, even at a maximum fat content of 31%. As this stage is regarded as the most important phase for deagglomeration during conching, qualitative analysis of the chocolate masses by light microscopy was used as a diagnostic. In this way we observed that complete destruction of all agglomerates in the chocolate masses had taken place, despite the lack of the pasty consistency during conching.

Using the IOCCC recommendations as standards, the viscosities and their s.d. (two conching trials of the same milk powder, each measured in duplicates) at shear rates 2, 5, 10, 20 and 50 s⁻¹ are given in Table 3. Despite some large s.d. in viscosities at low shear rates, Table 3 shows that two major groups of chocolate masses can be distinguished: one with relatively low and the other with relatively high mass viscosities. The viscosity of chocolate masses containing SP-A-LMF, SP-A-AMF and SP-A-HMF could only be measured at low shear rates due to their high viscosities.

Figure 1 Representative viscosity curves (measured at 45 °C) for chocolate masses produced with different milk powders.
Combining data from Tables 1 and 3 leads to the conclusion that the viscosities of the chocolate masses depend on the free fat content of the milk powders used. In Fig. 2 the viscosities obtained, using a shear rate of 10 s\(^{-1}\), are plotted against the free fat content of milk powders in g per 100 g chocolate mass. These were calculated according to the following equation:

\[
X = 26 \times (0.01 \times mf) \times t(0.01 \times fmf) \quad (1)
\]

where \(X\) is the viscosity (Pa s) at 10 s\(^{-1}\) of milk powder; \(mf\), free milk fat in wt (%) of total milk fat.

The higher the free fat content of the milk powder, the lower the viscosity of the chocolate mass. This effect occurred within each group of milk powders (SP-A, SP-B and RP), regardless of the milk fat fraction used. Fig. 2 shows that the influence of the free fat content of milk powders on the viscosity of the chocolate mass was not the same in all milk powder types. Small variations in the free fat content of spray-dried milk powder type B caused large variations in the viscosity of the chocolate mass, while this did not change

Table 3  Viscosities and their standard deviations at different shear rates according to IOCCC for chocolate masses produced with different milk powders

<table>
<thead>
<tr>
<th>Milk powders</th>
<th>2 s(^{-1}) (s.d.)</th>
<th>5 s(^{-1}) (s.d.)</th>
<th>10 s(^{-1}) (s.d.)</th>
<th>20 s(^{-1}) (s.d.)</th>
<th>50 s(^{-1}) (s.d.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP-A-LMF</td>
<td>76.05 (6.24)</td>
<td>43.10 (4.11)</td>
<td>29.98 (3.37)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SP-A-AMF</td>
<td>81.05 (10.15)</td>
<td>43.73 (2.38)</td>
<td>30.35 (2.55)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SP-A(GOLD)-AMF</td>
<td>24.66 (0.34)</td>
<td>12.34 (0.53)</td>
<td>8.25 (0.25)</td>
<td>5.93 (0.25)</td>
<td>4.35 (0.24)</td>
</tr>
<tr>
<td>SP-A-HMF</td>
<td>92.21 (8.66)</td>
<td>55.91 (4.20)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SP-skimmed</td>
<td>33.84 (7.35)</td>
<td>15.78 (3.50)</td>
<td>9.71 (1.84)</td>
<td>6.64 (1.41)</td>
<td>4.52 (0.83)</td>
</tr>
<tr>
<td>SP-B-LMF</td>
<td>48.56 (4.05)</td>
<td>24.95 (1.80)</td>
<td>16.16 (1.04)</td>
<td>11.15 (0.59)</td>
<td>NA</td>
</tr>
<tr>
<td>SP-B-AMF</td>
<td>24.50 (6.09)</td>
<td>15.81 (1.51)</td>
<td>10.23 (0.76)</td>
<td>7.17 (0.52)</td>
<td>5.05 (0.24)</td>
</tr>
<tr>
<td>SP-B-HMF</td>
<td>46.08 (4.71)</td>
<td>23.63 (1.76)</td>
<td>15.21 (1.52)</td>
<td>10.55 (0.95)</td>
<td>6.64 (0.09)</td>
</tr>
<tr>
<td>RP-LMF</td>
<td>30.97 (5.01)</td>
<td>14.12 (1.37)</td>
<td>8.66 (0.40)</td>
<td>5.86 (0.17)</td>
<td>4.02 (0.04)</td>
</tr>
<tr>
<td>RP-AMF</td>
<td>32.54 (1.46)</td>
<td>17.55 (0.28)</td>
<td>11.81 (0.34)</td>
<td>8.59 (0.22)</td>
<td>6.33 (0.12)</td>
</tr>
<tr>
<td>RP-HMF</td>
<td>22.67 (3.66)</td>
<td>11.33 (2.44)</td>
<td>7.22 (1.46)</td>
<td>4.97 (0.89)</td>
<td>3.52 (0.53)</td>
</tr>
<tr>
<td>RP-skimmed</td>
<td>24.88 (3.26)</td>
<td>12.42 (1.60)</td>
<td>7.71 (0.97)</td>
<td>5.23 (0.58)</td>
<td>3.62 (0.36)</td>
</tr>
</tbody>
</table>

NA, not available.

Figure 2  Viscosity of chocolate masses containing different milk powder types (SP-A, SP-B and RP) at a shear rate of 10 s\(^{-1}\) depending on the content of free fat related to the chocolate mass (measured at 45 °C).
significantly for the roller-dried milk powder. Spray-dried milk powder type A showed that low free fat contents led to very high viscosities in the chocolate mass. This effect has also been reported by Tscheuschner (1993b) who used model systems.

In contrast to what has been reported in literature so far (Hansen & Hansen, 1990), two spray-dried whole milk powders [SP-A(GOLD)-AMF and SP-B-AMF] showed viscosities in the chocolate mass comparable with those of products prepared when using roller-dried milk powders (RP-HMF and RP-LMF), particularly if almost the same level of free fat content and comparable particle size distributions were recorded.

Figure 3 shows SEM pictures of two spray-dried milk powder particles, one with a low (SP-A-AMF) and the other with a high [SP-A(GOLD)-AMF] content of free fat, as well as a roller-dried milk powder (RP-AMF). Comparison of the two spray-dried milk powders proves that the microstructure and the related availability of the milk fat play an important role for flow properties of chocolate masses. While SP-A-AMF shows a compact structure with a big hole in the centre, SP-A(GOLD)-AMF seems to have a spongy inner structure and free fat is available on the powder surface. Roller-dried milk powder (RP-AMF) shows, in contrast to the round-shaped particles of spray-dried milk powder, an irregular spongy shape. The absence of holes in the inner structure of the roller-dried powder explains its high content of free fat and thus its good flow properties in the chocolate mass.

Spray- and roller-dried skimmed milk powders with milk fat (MMF) added separately before refining showed comparable viscosities, if their s.d. are taken into consideration (Table 3 and Fig. 1). Also Dimick et al. (1996) reported that there was no significant differences in viscosity among chocolate masses at 40 °C, when milk fat was added separately to skimmed milk powder.

All these results lead to the conclusion that the free fat content of milk powders is the main factor influencing the viscosity in chocolate masses where
one type of milk powder was used. Comparison of SP-B and RP, both with HMF and LMF, supports the assumption that the effect of the free fat content in milk powders on the rheological properties of the chocolate mass is overlaid by other factors, such as interfacial properties and the macrostructure of the disperse phase. Although both types of milk powders had similar free fat contents, the difference between their viscosities was remarkable, while the viscosities in those two types using MMF separately, differed only within the s.d. This effect indicates that milk fat fractions behave differently in spray-dried and roller-dried milk powder.

Comparison of crystallization curves of chocolate masses produced with HMF, LMF, MMF and AMF (Fig. 4) shows the differences in their crystallization temperatures. While AMF started to crystallize at 22 °C, using MMF induced crystallization at 21 °C, crystallization occurred at 20.5 °C using low melting fractions (LMF) and at 24 °C using HMF. Although differences in crystallization temperature were only small, these crystallization temperatures were found in repeated measurements and duplicate conching runs and can therefore be regarded as significant. As reported by Kayligian (1997) and Reddy et al. (1996), it could be confirmed that chocolates containing high-melting milk fat fractions need to be tempered at higher temperatures, because of their higher crystallization temperature and this leads to an increased crystal amount at conventional crystallization conditions. Furthermore, it was shown, as reported by Reddy et al. (1996), that milk fat delays crystallization of cocoa butter. This effect is not the same for all milk fat fractions. HMF has a more similar chemical composition to cocoa butter than the other fractions and delays crystallization less than AMF or LMF. Chocolates produced with skimmed milk powders, where milk fat (MMF) was added in free form to the other ingredients, showed a higher ‘mixed crystallization’ between milk fat and cocoa butter. The crystallization peaks for milk fat and cocoa butter were not clearly separated. This can be explained by the fact, that in some samples MMF was available in free form. The absence of a mechanical barrier between the milk fat and the cocoa butter enabled mixed crystallization of the two fats. Furthermore, the triglycerides present in this fraction seem to show a higher similarity to those contained in cocoa butter. Differences in heat flow for cocoa butter (Fig. 4) are caused by non-homogeneous sample preparation.

As shown in Fig. 5, no difference in the melting and crystallization behaviour of the same milk fat incorporated in different milk powders was observed. The shape of the milk powder particles had no influence on the caloric qualities of milk fat and its fractions and did not affect their crystallization behaviour.

![Figure 4](image-url)  
**Figure 4** Representative crystallization curves of chocolate masses containing anhydrous milk fat (AMF), high- (HMF), low- (LMF) and middle-melting (MMF) milk fat fractions.
Conclusion

The free fat content of milk powders used for chocolate manufacturing was shown to have the main influence on rheological properties of chocolate masses. Other factors, such as microstructure and interfacial properties of the ingredients overlay this influence. The shape of milk powder particles, such as spray-dried or roller-dried milk powders, played an inferior role in rheological as well as in calorific properties of chocolate masses. New spray-dried milk powders from advanced technological processes enable production of chocolate masses with viscosities comparable with those made with roller-dried powders. However, incorporation of milk fat fractions might have an effect on interparticular interactions and thus on the rheology of the chocolate masses. The kind of incorporation described provides new possibilities for chocolate manufacturing and development of products of advanced flavour and quality.

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References


