Physical Stability of Spray-Dried Milk Fat Emulsion as Affected by Emulsifiers and Processing Conditions

S. Danviriyakul, D.J. McClements, E. Decker, W.W. Nawar, and P. Chinachoti

ABSTRACT: The effects of emulsifiers, wall, carbohydrate, and processing conditions on the physical properties of encapsulated powders were studied. Unstable emulsion causes an increase in the surface fat of spray-dried powder. Surface fat decreased with increasing DE and was unaffected by drying outlet temperature. A seven-fold decrease in surface fat was observed when the oil droplet size increased from 0.5 to 1.2 μm. At best, about 98% of the milk fat was encapsulated. Powder average particle size changed with outlet air temperature, oil droplet size, and DE. Particles contained air cells with some large voids and more spherical shape for 36 DE but dented and irregular shape for 10 DE.

Keywords: microencapsulation, maltodextrins, corn syrup solids, surface fat, dairy emulsions

Introduction

Milk fat is an economical source for producing new products such as dairy creamer, creamy condiments, and desserts. With fat being removed from many consumer products, milk fat market value dipped to a record low in early 1990’s (Lenz and others 1994; Hooker unpublished report). This was alarming for the dairy industry, and efforts were made to find value-added applications of milk fat. In this work, we explored the possibilities of encapsulating milk fat for making dairy creamer and other related products. The objective was to investigate ingredient and processing parameters that influence the physical stability of the spray-dried dairy emulsion. In a related investigation, the oxidative stability of the same encapsulated powders was investigated as a function of moisture and other physical factors (Hardas and others 2000). The underlying interest is the identification of the important factors that influence the physical stability of the powders and the relationships between physical stability (for example, oil droplet size distribution, powder morphology, fat distribution) and the oxidative events occurring in the lipid phase.

When encapsulated in a dry powder system, milk fat is isolated from the gaseous environment by wall materials. Physical structure of wall materials can influence the oxidative stability of the final product. Formation of surface wrinkles, scars, and damaged surfaces can lead to an increase in the amount of extractable fat, a feature that was suggested as due to mechanical stress developed during drying (Rosenberg and Young 1993). Less structural damage is obtained from elastic materials, that is, low molecular weight carbohydrates, that are more resilient to stresses. Optimizing the processing conditions and wall materials used would enable manufacturers to produce products with extended shelf-life.

The physical properties of liquid emulsions before spray drying are critical to the encapsulation of lipids. Obtaining a stable liquid emulsion is a prerequisite for proper encapsulation in spray-dried powders (Faldt and Bergenstahl 1995). In addition to common emulsifiers, proteins can facilitate the stabilization of emulsions. Formation and stability of an emulsion are greatly affected by the distribution of surface-active ingredients in the bulk phase and on the surface of the oil droplets. Major factors that contribute to a variation in the surface composition of emulsion droplets are 1) strength of interaction between surface-active species, 2) ratio between the total amount of surfactants present and the droplet surface area, and 3) competitive displacement of surfactants at the interface (Courthaudon and others 1991b; Mackie and others 1996). Hydrophilic-hydrophobic balance (HLB) is often used to describe emulsifiers and their effect on emulsion stability. However, results are often inconsistent (for example, Chow and Ho 1996), and investigation is needed to determine suitable emulsifier combinations for specific uses.

The objectives of this investigation were to study the effect of emulsifiers on the physical stability of dairy emulsions and the encapsulation efficiency of spray-dried milk fat powder or dairy creamer as a function of emulsion droplet size, wall material type, and drying temperature.

Materials and Methods

Anhydrous milk fat (99.9% milkfat) was supplied by Grassland Dairy Products (Greenwood, Wis., U.S.A.). Sodium caseinate (Alanate 110) was obtained from New Zealand Dairy products, Santa Rosa, Calif., U.S.A.), maltodextrins 10 and 20 DE (MW about 1800 and 900, respectively) from Grain Processing Corporation (Muscatine, Iowa, U.S.A.), corn syrup solid (CSS) 36 DE (MW about 500) from Roquette America (Keokuk, Iowa, U.S.A.), food grade lecithin with 32% acetone insolubles (Beakin L-3) from ADM Ross & Rowe Lecithins (Decatur, Ill., U.S.A.), distilled monoglycerides from ADM (DMG-40) from ADM Monoglycerides (Decatur, Ill., U.S.A.), and Tween 20 from CMS Champure (Houston, Tex., U.S.A.). Potassium phosphate dibasic and hexane were purchased from Fisher Scientific (Fairlawn, N.J., U.S.A.).

Liquid emulsion preparation

Oil-in-water emulsions of 30% (wt/wt) solid content were prepared containing 40.0% (wt/wt) milk fat, 7.5% (wt/wt) sodium...
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caseinate, 0.9% (wt/wt) potassium phosphate dibasic, 49.6% (wt/wt) carbohydrate (CSS with DE-36). Lecithin, monoglycerides, and Tween 20 at 0.5 to 2.0% based on dry basis were used as emulsifiers. The aqueous phase and the oil phase were prepared separately. Dry ingredients were mixed and dissolved in distilled water (50°C). Milk fat was warmed to 50°C; lecithin was then added to the melted fat. The 2 phases were mixed and emulsified to obtain a mean oil droplet size of about 0.5 to 0.6 mm using an ultrasonic generator (Braun-Sonic 2000U, Braun Biotech, Allentown, Pa., U.S.A.) equipped with a 5T standard probe. The emulsion was pasteurized at 65°C for 30 min then cooled in an ice bath. About 20 ml of emulsion were transferred into vials and stored at 4°C. Creaming index and particle size distribution of the emulsions were performed after 24 h of storage. The 24 h storage period was selected as the emulsion was normally stored overnight before spray drying.

Creaming index (%)

When the emulsions were placed in glass vials and stored at 4°C, phase separation into “cream” and “serum” phases was visually observed. The cream phase was droplet-rich because of the upward movement of the oil droplets, whereas the serum phase was droplet-depleted. The height of cream (H_C) and serum (H_S) layers were recorded after 24 h storage at 4°C (5 vials for each emulsion). Creaming index (%) was expressed as the percent volume ratio between serum layer and total emulsion: $\frac{H_S}{H_C + H_S}$.

Particle size measurement

Oil droplet size distributions of the liquid emulsions before and after storage (at 4°C) were analyzed using a laser scattering particle size analyzer (LA-900, Horiba, Instruments Inc., Irvine, Calif., U.S.A.). An emulsion was warmed to 50°C in a water bath before analysis to melt any crystalline fat droplets. Measurements were carried out on duplicate samples with 2 measurements each to determine the mean emulsion droplet size. At the point of measurement the emulsion was further diluted to less than 0.02% (wt/wt) to prevent multiple scattering effects. A refractive index ratio of 1.08 was used to calculate the mean oil droplet size.

Spray-dried emulsion preparation

Maltodextrins or CSS of three different molecular weights (10, 20, and 36 DE) were the major component of the wall materials. All ingredients and liquid emulsion preparation were the same as listed above, but lecithin was used at 2.0% (wt/wt) concentration. A coarse emulsion was prepared by blending aqueous and oil phases together using a high-speed blender (Waring Commercial Blender, Waring Products Division, New Hartford, Conn., U.S.A.) for 30 s at the highest speed. This coarse emulsion was then de-aerated in a water aspirator for approximately 30 min. The fine emulsion was prepared by homogenizing the coarse emulsion using a single stage valve homogenizer (APV-Gaulin, Model Mini-Lab 8.30H, Wilmington, Mass., U.S.A.) at 5000 to 6000 psi, depending on samples and pressure required to achieve a desirable oil droplet size distribution.

To study the effect of emulsion droplet size, emulsions were prepared with mean droplet dia of 0.5, 1.0, and 1.2 μm. To study the effect of spray drying temperature, average dia was maintained at 0.5 μm and the outlet temperature was varied from 75 to 95°C range.

The emulsion was pasteurized at 65°C for 30 min, cooled and stored at 4°C prior to spray drying. With an exception of the drying temperature study, all spray drying was performed at 210°C inlet and 95°C outlet temperatures at a feeding rate of 2 liters per hr using a Niro spray dryer equipped with a centrifugal atomizer (Nerco-Niro, Nicolas & Research Engineering Corporation, Copenhagen, Denmark). Finished powder (about 1% moisture) was immediately mixed with 1% (wt/wt) SiO2 and stored in a hermetically sealed laminated pouch (filled with nitrogen gas) at -40°C until analysis.

Fat extraction

The encapsulation efficiency was determined from the amount of surface fat (easily extractable fat) measured after hexane extraction. Fifteen ml of hexane were added to 2.5 g of powder in a 30 ml glass vial. They were mixed with a Vortex mixer (Vortexer 2, VWR Scientific Products, Boston, Mass., U.S.A.) for 2 min and then centrifuged (Size 2, Model K, International Equipment Co., Needham Hts., Mass., U.S.A.) at 2720 G for 20 min. The supernatant was filtered with a filter paper (Whatman 2V). The filtrate was dried under a flow of nitrogen gas until a constant weight was obtained (about 3 h). This weight was expressed as the percent of extractable fat on total fat basis.

Scanning Electron Microscopy

Internal and surface morphology of the powdered was evaluated by Scanning Electron Microscopy (SEM). For the surface morphology, the method reported by Rosenberg and others (1985) was used. Ten mg of the powder was dispersed in 2 ml of LR-White resin and incubated under UV-light (about 365 nm) for 24 h to polymerize the resin. The block containing embedded powder was sectioned by ultramicrotome (Potter Blum Ultra-Microtome MT-2, Ivan Sorvall, Inc., Norwalk, Conn., U.S.A.) to expose the cut surface and then mounted onto a specimen stub using epoxy resin as a binder. All specimens were coated with palladium/gold before observation. The images were viewed by scanning electron microscopy at 3.0 kV (JEOL 5400, JEOL, Japan). Five frames of pictures of each sample were taken to represent the structure of the powders.

Powder particle size

After spray-drying, the powder was mounted onto the slide using 2-sided sticky tape. Excess powder was removed to form single powder layer. This was to avoid the focusing problem that may affect the size measurement when multiple layers exist. The microscope (Eclipse E400, Nikon Inc., Melville, N.Y., U.S.A.) equipped with Dage-MTI RC300 CCD camera (Dage-MTI Inc., Michigan City, Ind., U.S.A.) was used to acquire the powder image. The picture of powder was taken at 40X magnification and stored in the computer for further analysis. Black and light gain levels were adjusted to enhance the contrast between powder structure and background. The particle size was then measured using an image analysis software program (Mocha®, Jandel Scientific, San Rafael, Calif., U.S.A.). For a round structure of DE-20 and DE-36 samples, the dia was measured directly from the farthest distance between 2 points. Feret dia calculated as (4xarea/π)1/2 was used to determine the particle dia of DE-10 sample instead due to its structural irregularity. Mean particle dia was obtained from the average of about 800 to 1000 particles of each powder (from 2 to 3 replicates).

Emulsion oil droplet size

Oil droplet size of powder after spray drying was measured from reconstituted emulsion. The powder was reconstituted to 10 g solids per 100 g reconstituted emulsion by dissolving 0.5 g of powder in 4.5 ml of 50°C distilled water. One h after reconstitution, the emulsion was analyzed for oil droplet size distribution using the same conditions previously described.
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Table 1—Effects of emulsifier types and concentrations on the mean oil droplet dia and creaming index of liquid emulsions at 0 and 24 h of storage.

<table>
<thead>
<tr>
<th>Emulsifiers</th>
<th>Emulsifier concentration (%)</th>
<th>Mean oil droplet dia (μm)</th>
<th>Mean oil droplet dia ratio (24hr/0hr)</th>
<th>Creaming index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total basis</td>
<td>Dry basis</td>
<td>0 hr</td>
<td>24 hr</td>
</tr>
<tr>
<td>Lecithin</td>
<td>0.15</td>
<td>0.5</td>
<td>0.56a</td>
<td>0.56a</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>1.0</td>
<td>0.56a</td>
<td>0.55a</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>2.0</td>
<td>0.56a</td>
<td>0.56a</td>
</tr>
<tr>
<td>Monoglycerides</td>
<td>0.15</td>
<td>0.5</td>
<td>0.57a</td>
<td>1.37h</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>1.0</td>
<td>0.58b</td>
<td>1.71b</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>2.0</td>
<td>0.58a</td>
<td>0.62a</td>
</tr>
<tr>
<td>Tween 20</td>
<td>0.15</td>
<td>0.5</td>
<td>0.57a</td>
<td>0.57a</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>1.0</td>
<td>0.59a</td>
<td>0.59a</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>2.0</td>
<td>0.60a</td>
<td>3.43c</td>
</tr>
</tbody>
</table>

Means with the same letter are not significant difference (α = 0.05).

Statistical analysis

For the liquid emulsion study, a 3 x 3 factorial design of 3 emulsifiers and 3 concentrations was conducted. The effects of wall material types, oil droplet size, and spray-drying temperature were studied separately. When one factor was studied the other factors were maintained constant. Three replicated emulsions and powders were prepared. The analyses were done in duplicates for each treatment. Results were analyzed using the General Linear Models (GLM) procedure (SAS). The Duncan test was performed to establish significant differences between mean values (α = 0.05).

Results and Discussion

Liquid emulsion

Emulsion physical properties were monitored in terms of creaming index and oil droplet size distribution at 0 and 24 h of storage at 4 °C. The effects of emulsifier type and concentration are shown in Table 1. A low creaming index value indicated better emulsion stability. Most of the emulsions did not form a cream layer after 24 h except the one containing 0.60% (wt/wt) Tween 20. In this emulsion, a cream layer formed immediately after the emulsification process and reached about 57% at the end of storage. One possible explanation of this phenomena is that the Tween 20 displaced the casein from the oil-water interface, and that the displaced protein promoted depletion flocculation of the droplet (Dickinson and Golding 1997).

The effects of emulsifier type and concentration on the mean emulsion droplet size was also measured (Table 1). The oil droplets in emulsions containing lecithin at all concentrations were relatively stable to aggregation, that is, there were no significant changes in the mean droplet size after 24 h period. Emulsions made from monoglycerides were not free from aggregation even though they did not give rise to formation of a cream layer. At 0.15% (wt/wt) total basis, the measured particle size after 24 h of storage was more than double (Table 1). Very little aggregation was found at the highest concentration, complete protein displacement by surfactants may lead to destabilization of an emulsion. The mechanism of destabilization is rather complex in food emulsion systems and varies among different types of proteins (caseins compared with whey proteins) and small molecule emulsifiers (oil-soluble compared with water-soluble) (Courthaudon and others 1991b). Excellent emulsifying properties of lecithin are known for its tendency to form lamella mesophases and vesicles in aqueous media and produce lipid-protein complexes (Bergenstahl and Claesson 1997; Courthaudon and others 1991a). Adsorption of lecithin to droplet surfaces stabilized by casein molecules has been shown to cause the extension of the caseins into the aqueous phase. At low concentration, lecithin had little effect on protein displacement. Courthaudon and others (1991a) reported that the amount of adsorbed proteins in soy oil emulsion remained unchanged up to lecithin to protein molar ratios (R) of 20, which is equivalent to 0.3% (wt/wt) of pure lecithin in the presence of 0.5% b-casein. In this experiment, even at the highest concentration of lecithin, the R-value was still lower than this number, which suggests that it would not displace the casein. Emulsions made with lecithin showed a very good stability against creaming and coalescence.

Stabilization of emulsion by proteins was enhanced by increasing the monoglyceride concentration. The improved stability with respect to creaming and coalescence of emulsion droplets by monoglycerides has been suggested to be associated with a change in bulk rheological properties of the emulsions due to complex formation between monoglycerides and caseins in bulk aqueous solutions and at the interface (Dickinson and others 1989; Euston and others 1996). Displacement of proteins by monoglycerides or other small surfactant molecules suggested a detrimental effect on the emulsion stability (Courthaudon and others 1991b; Dalgleish and others 1995; Euston and others 1996). In our study, an increase in emulsion stability was observed with increasing monoglyceride concentration. The highest concentration (0.60%, wt/wt) used in this study might not have been high enough to cause any adverse effect. The mixture of monoglycerides used in our study probably led to a more complex stabilization mechanism than that of a single monoglyceride molecule reported elsewhere.

Many molecular mechanisms are involved in determining the physicochemical properties of protein stabilized emulsion contain-
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Spray-dried emulsion

Effect of emulsion droplet size. Emulsions containing corn syrup solids (CSS) with DE-36 and 2.0% (dry basis) lecithin were prepared to obtain various oil droplet size distributions (average dia 0.5, 1.0, and 1.2 μm). Particle size distributions and extractable fat were obtained from powder prepared from emulsions with various oil droplet sizes. Liquid emulsions were spray dried at 95 °C outlet temperature. Varying oil droplet size did not have an effect on powder particle dia profiles (Figure 2) but extractable fat (surface fat) on the other hand increased significantly (α = 0.05) with increasing oil drop–

Effect of drying temperature. Milk fat emulsion containing 0.60% (total fat basis, wt/wt) lecithin and DE-36 was investigated with three spray drying outlet temperatures, 75, 85, and 95 °C (or 160, 180, and 210 °C inlet temperature, respectively). Spray-drying temperature was found to affect powder particle dia profiles (Figure 2) but not extractable fat (α = 0.05). Increasing the spray drying temperature resulted in an increase in the powder particle size distribution (Figure 2). In all cases, the amount of extractable fat was less than 2% (total fat basis, wt/wt).

Drying temperature had little effect on the structure of the powder based on scanning electron microscopy (Figure 3). All powder samples showed spherical morphology with some wrinkles or scars on the surface (Figure 3 A, C, and E) and some large internal voids (cross sectioned, Figure 3 B, D, and F). Slightly more wrinkles were observed, however, in the powder spray-dried at lower temperatures. This might have been due to some mechanical stress induced by uneven drying at different parts of the drying droplets and by shrinkage of casein (Rosenberg and Young 1993). The formation of dents is believed to occur at the early stages of the drying process.

Effect of wall material. The drying process was found to have an impact on the stability of the oil droplets in reconstituted emulsion. But this also depends on the carbohydrates used for the wall material. Figure 4 shows the influence of spray drying on oil droplet size distributions shortly before spray drying and after drying. Significant increases in the mean oil droplet population were observed after drying and reconstitution. For emulsions initially containing 0.5 μm droplets, spray drying did not cause a change in the particle size distribution after reconstitution. For emulsions initially containing 1 μm droplets, spray drying caused a change in the particle size distribution after reconstitution that depended on DE. At low DE (DE 10), the emulsion still had a monomodal distribution but the mean size increased slightly. At higher DE (DE 20 and 36), a bimodal distribution occurred, indicating the formation of some large droplet particles. DE-36 carbohydrate was most favorable because it resulted in less enlargement of oil droplets after drying. The effect of DE could be related to an ability to stabilize the protein by small sugars, which were present in a higher quantity in the case of

Figure 1—Extractable fat of spray-dried milk fat emulsions prepared with 0.5, 1.0, and 1.2 μm average oil droplet dia. All emulsions contained 40% milk fat, 50% DE-36 CSS, and 2% lecithin, dry basis. The emulsions were spray-dried at 95 °C (outlet temperature).

Figure 2—The effect of drying temperature on powder particle size distributions of spray-dried milk fat emulsions. All emulsions contained 40% milk fat, 50% DE-36 CSS, 2% lecithin, dry basis, and 0.5 μm average oil droplet dia.
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DE-36. Exposure to a high drying temperature could lead to a change in casein surface activity. Small carbohydrates have been reported to have a thermal stabilizing effect on proteins and thus reduce the loss in surface activity due to drying (Faldt and Bergenstahl 1995; Young and others 1993a; Young and others 1993b). Water loss from protein molecules during drying may lead to protein denaturation and leaking of the encapsulated film. Partial displacement of water by the addition of low molecular weight saccharides (osmotic effect on water by solutes) (Record and others, 1998) such as lactose may enhance protein aggregation and thereby increase the stability of the protein film.

The effects of carbohydrate DE (maltodextrins or CSS) on powder particle size distribution and the amount of extractable fat are shown in Figure 5 and 6. The particle dia of these powders was found in the range of 1 to 30 μm (Figure 5). Powder particle size was affected by DE. Larger powder particle size with an irregular shape was obtained from lower DE (Table 2). From Figure 7, powders made from DE-36 showed a spherical structure with a few wrinkles on the surface. More wrinkles were observed with the powder with smaller DE values. Irregular shape with deep surface dents was normally seen in the powder with DE-10. There was no difference

Figure 3—SEM micrographs of spray-dried milk fat emulsion showing outer and inner structures of samples containing 40% milk fat, 50% DE-36 CSS, and 2% lecithin, dry basis. 75 °C: (A) and (B), 85 °C: (C) and (D), and 95 °C: (E) and (F).

Figure 4—Influence of carbohydrate DE and spray drying (95 °C outlet temperature) on oil the droplet size distribution (l) before spray drying and (m) after spray drying and reconstitution.

Figure 5—The effect of carbohydrates used on powder particle size distribution of spray-dried milk fat emulsions. All emulsions contained 40% milk fat (dry basis) with an average oil droplet dia of 0.5 μm, and spray dried at 95 °C outlet temperature.
in internal structure of these powders within variation due to scattered distribution of small air cells found throughout the powder particle together with some large voids.

The amount of extractable fat was the lowest in the powder made with DE 36 (2% surface fat) and this significantly increased with decreasing DE (to 25% surface fat for the case of DE-10, Figure 6). This was not surprising because it was shown earlier (Figure 4) that the presence of wall materials with a larger molecular weight (for example, DE-10) resulted in a major increase in average oil droplet size upon spray drying. This was possibly due to a lack of thermal stabilization effect of the carbohydrates on the surface active casein moieties leading to a significant decrease in emulsion stability. Maintaining emulsion stability throughout the process is thus a prerequisite for a high encapsulation efficiency of the lipids. Increased encapsulation efficiency on volatile retention has been shown when smaller MW carbohydrates are used. For instance, Onwulata and others (1996) reported that sucrose offered the best encapsulation of milkfat powder followed by modified starch and native starch, respectively. Higher volatile retention has been found with wall materials with a low molecular weight (for example, glucose and maltose) than those with a higher molecular weight, for example, polyvinylpyrrolidone and dextran (Chirife and others 1973).

Variations in the amount of extractable fat may be affected by differences in molecular structure of these ingredients. Formation of a continuous phase in the presence of small molecular weight carbohydrate is suggested to provide a barrier against fat extraction (Moreau and Rosenberg 1993). Viscosity increase of drying materials changes the physical state of these materials from liquid to rubbery and eventually to glassy state. Since the higher Tg is expected for maltodextrin of DE-10, the sample would turn glassy earlier followed by DE-20 and then DE-36. A more rapid increase in viscosity at the early stage of drying in the presence of maltodextrin DE-10 may retard the formation of impermeable microregions entrapping the encapsulated material (Chirife and others 1973). With a lower viscosity, structural collapse in the higher DE samples (DE-20 and DE-36) could lead to a formation of a denser wall matrix around the fat droplets preventing the accessibility of fat by the solvent and therefore lowering the amount of extractable fat.

There is no doubt that dynamic physical changes in the drying step played an important role here. The inter-relationships among molecular weight (hence viscosity), temperature, and volatility of water have a tremendous impact on the powder integrity and encapsulation efficiency. For instance, the presence of deep surface dents could be eliminated by drying the powder more rapidly. Thermal expansion of the air and water vapors inside the drying particle can erase the dents after ballooning, as the material gives way to the steam. However, after each ballooning, the elastic wall sys-

![Figure 6](image_url)

**Figure 6**—The effect of carbohydrates used on the amount of extractable fat (% based on total fat) of spray-dried milkfat emulsions. All emulsions contained 40% milk fat (dry basis) with an average oil droplet dia of 0.5 μm, and spray dried at 95 °C outlet temperature.

![Table 2](image_url)

**Table 2**—Effects of wall materials and processing conditions on the mean powder particle size. Powders contained 2% (wt/wt, dry basis) lecithin.

<table>
<thead>
<tr>
<th>Effect of</th>
<th>Mean powder particle size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE type (dia about 0.5 μm and 95 °C outlet temperature)</td>
<td></td>
</tr>
<tr>
<td>DE-10</td>
<td>11.5 ± 3.9^a</td>
</tr>
<tr>
<td>DE-20</td>
<td>10.9 ± 4.3^b</td>
</tr>
<tr>
<td>DE-36</td>
<td>11.1 ± 4.0^b</td>
</tr>
<tr>
<td>Drying temperature (outlet) (dia about 0.5 μm and DE-36)</td>
<td></td>
</tr>
<tr>
<td>75 °C</td>
<td>9.7 ± 4.6^a</td>
</tr>
<tr>
<td>85 °C</td>
<td>10.8 ± 4.9^b</td>
</tr>
<tr>
<td>95 °C</td>
<td>11.1 ± 4.0^b</td>
</tr>
<tr>
<td>Emulsion droplet dia (DE-36 and 95 °C outlet temperature)</td>
<td></td>
</tr>
<tr>
<td>0.5 μm</td>
<td>11.1 ± 4.0^a</td>
</tr>
<tr>
<td>1.0 μm</td>
<td>10.8 ± 4.5^a</td>
</tr>
<tr>
<td>1.2 μm</td>
<td>12.0 ± 4.6^b</td>
</tr>
</tbody>
</table>

Means with the same letter are not significant difference (α = 0.05).
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Conclusions

Emulsifier Type and Concentration are Key Factors in Creating Dairy Emulsions that will Survive Harsh Processing Conditions, such as a High Heat Treatment. A Stable Emulsion is a Pre-Requisite for a High Encapsulation Efficiency of Milkfat in Spray-Dried Powders. In this Work, as Much as 98% of Total Fat was Encapsulated Using 0.60% Lecithin, Casein, and CSS at DE-36. De-Stabilization of the Emulsion with Tween 20 was Probably Caused by the Displacement of Proteins from the Interface by the Emulsifier.

Inadequate Emulsification Caused Larger Oil Droplets and Led to Lower Encapsulation Efficiency. Additionally, Molecular Weights of the Wall Carbohydrates and the Presence of Smaller Sugars are Important in Protecting Casein Functionality and Preventing Undesirable Loss in the Surface Activity that Otherwise Would Occur with Heat Exposure at Drying Temperature. Among 3 Different Types of Wall Materials, CSS of DE-36 Showed the Highest Encapsulation Efficiency. The Powder Maintained its Initial Oil Droplet Size Distribution After Drying and Had Good Powder Integrity (Less Powder Surface Defects). Lower DE was Found to Lead to Poorer Emulsion Stability, Higher Surface Fat, and Powder with Surface Defects and Irregular Geometry. Flow Properties of the Wall Materials During Spray Drying are Suggested to Play a Role in Wrinkle Formation.

References


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