LWT - Food Science and Technology 68 (2016) 653–658

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Effect of fat replacement on flow and thermal properties of dairy powders

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A R T I C L E I N F O

Article history:
Received 30 June 2015
Received in revised form
15 December 2015
Accepted 29 December 2015
Available online 1 January 2016

Keywords:
Dairy powders
Milk fat
Palm oil
Flowability
DSC

A B S T R A C T

This paper presents the influence of fat replacement on flow and thermal properties of dairy powders. The research was undertaken by measuring flow properties of four different milk powders (whole milk powder, skim milk powder and two fat-filled milk powders with palm oil at 6.63 g/100 g and 25.5 g/100 g fat content, respectively) by using shear test. Fat content has a major influence on milk powder cohesiveness, with greater content resulting in greater cohesiveness. Fat content and type has also significant influence on flowability of milk powder. Fat-filled spray-dried milk powder is characterized by better flowability than whole milk powder with the same content of fat. The DSC curves showed that milk fat tended to melt in a lower temperature region than vegetable fat.

1. Introduction

Considerable increase in the use of powders in food products forces the necessity to expand our knowledge concerning the conditions and characteristics of their processing (Fitzpatrick, Iqbal, Delaney, Twomey, & Koegh, 2004; Teunou, Fitzpatrick, & Synnott, 1999). The intended use of powders as food products and their mechanical properties, including rheological ones, implicate a range of requirements concerning designing of installations for transport, storage and packaging (Fitzpatrick, Barringer, & Iqbal, 2004; Horabik & Grochowicz, 2002; Szulc & Lenart, 2010). Mechanical properties of powders depend on the parameters of technological processes and storage conditions. Chemical composition of powders, including their fat content (mainly surface fat), is also of special importance (Ganesan, Rosentrater, & Muthukumarappan, 2008; Iqbal & Fitzpatrick, 2006; Murrieta-Pazos et al., 2011).

An important aspect in powder processing technology is flowability and reaction to consolidation (Szulc & Lenart, 2010). Powder flowability depends first of all on size and shape of its particles and on cohesive forces observed between them (Horabik & Grochowicz, 2002). Practical problems resulting from disturbances during their flow, such as formation of powder overlaps in chambers, incomplete flow, or tank outlet crusting, occur during loose materials utilization. Recognition of mechanical properties of powder is essential in solving such problems (Fitzpatrick, Iqbal et al., 2004; Schwedes, 2002).

The parameters of plastic flow characterize the conditions in which powders loose the properties characteristic for solids and start to behave like liquids (Horabik & Grochowicz, 2002; Opaliński, Chutkowski, & Stasiak, 2012). These parameters include effective angle of internal friction, kinetic angle of internal friction, compression strength, cohesion, and flow index. Analysis of plastic flow parameters enables determination of mechanical properties of examined powders (Fitzpatrick, Barringer et al., 2004; Fitzpatrick, Barry et al., 2007; Fitzpatrick, Iqbal et al., 2004; Horabik & Grochowicz, 2002). The method of direct shearing, used in friability studies, allows determining conditions and character of plastic flow of powdered materials. It also finds a practical application in designing storage tanks (determination of minimum inlet diameter guaranteeing undisturbed flow of powder) (Fitzpatrick, Barringer et al., 2004).

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http://dx.doi.org/10.1016/j.lwt.2015.12.060
0023-6438/

Most dairy products from spray-dryers are amorphous. For example, milk powders contain lactose in its amorphous state. Amorphous components are thermodynamically unstable and in a state of high energy, thereby making them more likely to convert to a more stable crystalline form, which causes difficulties in processing and storage. Crystallisation occurs only when the powder temperature is greater than its glass transition temperature, whereby the molecules have sufficient mobility to initiate crystallisation. The crystallisation may be preceded by the formation of liquid bridges between powder particles, which increase cohesiveness and caking ability of the powder (Ebrahimi & Langrish, 2015; Fitzpatrick, Barry et al., 2007; Fitzpatrick, Iqbal et al., 2007). Caking is a phenomenon whereby free-flowing particles aggregate to form larger lumps of particles through a time-dependent process, usually to the detriment of powder handling and quality (Descamps, Platzer, Roos, & Fitzpatrick, 2013). Therefore, an understanding of the flow behaviour and the knowledge of glass transition temperature is important to predict the quality of milk powders.

The aim of this study was to determine the effect of fat type and content and on flowability and thermal properties of dairy powders.

2. Materials and methods

2.1. Materials

Four industrial-scale milk powders obtained from OSM Koło (Koło, Poland) were studied. The fat content was measured respectively for skim milk powder (SMP) (0.40 g/100 g), whole milk powder (WMP) (26.0 g/100 g) and two fat-filled milk powders: with low vegetable fat (palm oil) content – 6.63 g/100 g total mass (LVMP) and high – 25.50 g/100 g (HVMP). A fat-filled is an economical replacer of milk powders, especially whole milk powder based upon vegetable fat. Main applications for fat-filled milk powder include: ice cream, bakery, confectionery, chocolate, biscuits, bread and cookies.

2.2. Powder properties

Water content was measured by mass (1 g of sample) loss after drying at 105 °C for 4 h. Water activity was measured by using a Rotronic HydroLab C1 (Rotronic AG, Bassersdorf, Germany) at temperature 24 ± 1 °C. Particle size distribution was determined by laser diffraction using a Cilas Particle Size Analyzer 1190 (Cilas, Orleans, France) and the results expressed as the median particle size (D_{50}). Loose and tapped bulk density was measured using a volumeter (J. Engelsmann A.G., Ludwigshafen, Germany), where the volume of a given mass of powder after 100 taps was measured to calculate the tapped bulk density (Szulc & Lenart, 2010). Particle density was measured using a gas stereopycnometer (Quantachrome Instruments, Boynton Beach, FL, USA). A sample was placed in the sample cell and degassed by purging with a flow of dry gas (helium) by a series of pressurization cycles. Porosity of the sample was calculated using the relationship between the tapped bulk density and particle density of the powder (Szulc & Lenart, 2013). Wettability (A/S Niro Atomizer, 1978) with modification: 100 mL of distilled water (at 21 °C) was poured into a beaker. A powder sample (10 g) was placed around the pestle (inside the funnel so that it blocked the lower opening) and lifted the pestle and a stopwatch was started. Finally, time was recorded when the powder became completely wetted (visually assessed when all the powder particles penetrated the surface of the water).

2.3. Flow properties

Direct shear tests were conducted using an apparatus with 95 mm diameter (Apek, Warsaw, Poland) (Jenike, 1964). The tests were performed following the procedure of consolidating stress 17.33 kPa and shearing speed of 1 mm min^{-1}. The yield locus was obtained by measuring the horizontal stress required to make the powder fall at the following normal stresses: 17.33, 13.17, 9.01 and 4.86 kPa. The values of unconfined yield strength (UYS), major consolidation stress (MCS), angle of internal friction, effective angle of friction and cohesion were obtained from Mohr's circles. The relationship between UYS and MCS regarded as a flow function was also calculated (Ganesan et al., 2008; Schwedes, 2002).

2.4. Thermal properties

Before the calorimetric experiments, all samples were dried for 24 h in a vacuum under pressure of 13 kPa and at temperature of 40 °C. The dairy powders were stored in a desiccator until measurement. Water activity of samples was close to the value of water activity of $CaCl_2$ at 25 °C. Dairy powders were studied by DSC (DSC, TA Instruments Q 200, USA) in a normal pressure cell. The cell was purged with dry nitrogen at 50 mL/min and calibrated for baseline on an empty oven and for temperature using standard pure indium. Specific heat capacity was calibrated using a sapphire. Samples were cooled with a mechanical refrigeration cooling system (intracooler). An empty sealed aluminium pan was used as a reference in every test. The dairy powders (10–15 mg) were non-hermetically sealed in aluminium pans and heated from −60 °C up to 240 °C with the heating rate of 5 °C/min. The DSC technique was used to obtain curves of heat flow (Wg^{-1}) versus temperature curves (DSC curves) (Ostrowska-Ligęza, Górska, Wirkowska, & Koczoń, 2012).

2.5. Statistical analysis

All measurements were made in triplicate for each sample. Results are expressed as mean ± standard deviations (SD). A one-way analysis of variance (ANOVA) and Tukey's test ($P < 0.05$) were used to establish the significance of differences among the mean values of the physical, flow and thermal properties of the spray-dried powders. The data were analysed using the Statgraphics Plus 5.1 version software (StatPoint Technologes, Inc., Warrenton, VA, USA).

3. Results and discussion

3.1. Powder properties

Water content in milk powders was below 5 g/100 g and was significantly lower for the powders filled with palm oil (HVMP, LVMP) compared to milk powders containing milk fat (WMP, SMP) (Table 1). Further increase in palm oil content in the powder did not result in lowering water content. Lower milk fat content in powdered milk resulted in decrease in its water content. The reverse relationship was presented in the study by Fitzpatrick, Barry et al. (2007). Martins and Kieckbusch (2010) also concluded that water content in maltodextrin powders with palm oil decreases with an increase in their oil content. Lowering of water content in LVMP in comparison to SMP was observed in the study. SMP was characterized by considerably lower water activity than WMP (Table 1). Water activity of powders containing palm oil (HVMP and LVMP) was significantly lower than that in powders containing milk fat (WMP and SMP). Water activity of milk powder with added palm oil, i.e. HVMP and LVMP, was similar to that