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Influence of water activity on the compressibility and mechanical properties of cocoa products

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ABSTRACT

The work described in this paper investigated influence of content (cocoa, crystal and sugar powders, milk powder and maltodextrin) and water activity (at three levels of 0, 0.34 and 0.65) on compressibility and mechanical properties of cocoa products. The flow characteristics of powders were determined according to the Jenike test. Compression test was done by ZWICK 1445 at the compressive stress of 5.34 kPa. Ingredients of cocoa powder beverages are characterized by very diverse particle size distribution and bulk density which in turn has an influence on relative humidity of powders. An increase of water activity in powders causes an increase in cohesion for all powders. Particle size has an influence on the values of cohesive forces and compressibility ratio. The increase of water activity in powders causes the increase of flow index. The increase of normal consolidating stress for cocoa causes the increase of flow index. Crystal sugar has the greatest values of flow index at all the levels of water activity.

1. Introduction

Powdered food is durable, convenient and easy to use. It is an excellent example of concentrated food – fast to prepare or often ready to eat, and with a relatively long shelf life (Chang, Kim, & Kim, 1997; Ostrowska-Ligęza, Lenart, 2000). As there is a large quantity and variety of foodstuffs mass-produced in powdered form, there is a need for information about their production, handling and processing characteristics. Measurement of powder properties is important because these properties intrinsically affect powder behavior during storage, handling and processing (Shrestha, Howes, Adhikari, & Bhandari, 2007). Powder flow properties are important in handling and processing operations, e.g. the flow from hoppers and silos, transportation, mixing, compression and packing (Fitzpatrick, Barringer, & Iqbal, 2004; Knowlton, Carson, Klinzing, & Yang, 1994; Peleg, 1978; Teunou & Fitzpatrick, 2000). One of the major industrial powder problems is obtaining reliable and consistent flow out of hoppers and feeders without excessive spillage and dust generation. These problems are usually associated with the flow pattern inside the silo. The worst case scenario is no flow. This can occur when the powder forms a cohesive arch across the opening, which has sufficient strength within the arch to be self-supporting. Mass flow is the ideal flow pattern where all the powder is in motion and moving down through the opening. Funnel flow is where powder starts moving out through a central "funnel" that forms within the material, after which the powder against the walls collapses and moves through the funnel. This problem continues until the silo empties or until another no-flow scenario occurs with the development of a stable rathole. Most flow problems are caused by a funnel flow pattern and can be cured by altering the pattern to mass flow (Domian, Koper, & Lenart, 2004; Johanson, 2002; Fitzpatrick, Barringer, et al., 2004; Fitzpatrick, Iqbal, Delaney, Twomey, & Keogh, 2004; Fitzpatrick et al., 2007).

Jenike (1964) pioneered the application of shear stress cell techniques for measuring powder flow properties. In conjunction with the measured property data, he applied two-dimensional stress analysis in developing a mathematical methodology for determining the minimum hopper angle and hopper opening size for mass flow from conical and wedge shaped hoppers. The measured flow properties used in this methodology are the flow-function, the effective angle of internal friction and the angle of wall friction. The flowfunction is a plot of the unconfined yield strength of the powder versus major consolidating stress, and represents the

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strength developed within the powder when consolidated and which must be overcome in making the powder flow. The flow index (ff_c) is defined as the inverse slope of the flowfunction. Jenike used the flow index to classify powder flowability with higher values representing easier flow (Tomas & Schubert, 1979). As the relative humidity of the surrounding air is increased, powders tend to absorb water which may form liquid bridges between powder particles and result in greater powder cohesion and reduced flowability. Conversely, as the relative humidity decreases, the powders tend to desorb water and liquid bridges to disappear. However, with most food powders being soluble materials, such as salt and sugar, solid bridges may remain and cause a powder cake. In addition, increasing the temperature of food powder increases dissolution of particles and this may facilitate changes in crystalline form that can result in caking and flow problems (Teunou, Fitzpatrick, & Synnott, 1999; Teunou & Vasseur, 1996). Adsorption of water from the atmosphere by a mass of powder is time-dependent because water must diffuse from the air into the powder and thus the effect of relative humidity on powder flowability will depend on the time required for moisture to diffuse. Eventually, such moisture content is obtained which provides a dynamic equilibrium between water in the powder and water in the air. Similar time-dependency occurs for temperature because heat must be conducted through the mass of powder and this takes time (Teunou et al., 1999). Water activity has been considered as one of the most influential factors in the safety and stability of foods (Przybył, Ćwiertniewski, & Egierski, 1998). The relationship between water activity and microbial growth, the kinetics of deteriorative chemical reactions and other quality factors have been investigated and reported (Falkowski, Warzecha, & Jakubowska, 1998). The physical aspects of water activity have also received considerable attention especially in foods containing sugar, renowned for their hygroscopic nature and tendency to agglomerate and stick (Domian & Poszytek, 2004; Moreyra & Peleg, 1981). The property of amorphous sugar to absorb considerable moisture (Makowerm & Dye, 1956; Ostrowska-Ligęza & Lenart, 2000; Teunou et al., 1999) and then to liberate moisture is probably one of the key reasons for physical instability in a variety of food powders even though crystallization of the sugars is frequently inhibited by other chemical components. Since many food powders are fairly fine, their solid density is relatively low and their bulk properties may be significantly affected by comparatively minor changes in surface moisture. In such cases (e.g. crystalline powders) water activity is expected to be a more sensitive indicator than the moisture content (Moreyra & Peleg, 1981; Ostrowska-Ligęza & Lenart, 2000). The selected method may depend not only on mechanical and chemical properties of the product, but also on the scale of the process under study, the type of material handled, whether the method will be used for quality control or for bin design, and whether arch formation and rathole formation are taken into consideration (Bell, 2001; de Jong, Hoffman, & Finkers, 1999; Juliano, Muhunthan, & Barbosa-Canovas, 2006). Properties such as angle of internal friction, cohesion, unconfined yield stress, compressibility, the Hausner ratio, bulk and tapped density have been used as qualitative descriptors of the flowability of food powders (Barbosa-Canovas, Malave-Lopez, & Peleg, 1987; Domian & Poszytek, 2004; Juliano et al., 2006; Konstance, Onwulata, & Holsinger, 1995).

The objective of this paper is to analyze flow properties of chosen food powders and to analyze the influence of powder type and water activity of selected powdered cocoa products on their flow properties and compressive stress. The scope of this work extended also to analyzing physical properties (particle size, bulk and tapped density, water activity) of the food powders under investigation.

2. Materials and methods

2.1. Investigated powders

The powders tested were: cocoa powder (Grekens Cocoa Bv Wormer, Holland), crystal sugar (Sugar Factory, Tuczyn, Poland), powdered sugar (Sugar Factory and Refinery, Chybie. Joint-Stock Company, Poland), whole milk powder (, District Cooperative Dairy in Turek, Poland), 9.5 DE maltodextrin (, Novoamyl S.A. (Joint-Stock Company) – Potato Processing Plant, Lobez, Poland). The powders were moistened in a dessicator at 0.34 and 0.65 water activity levels.

2.2. Physical properties

- Water activity (W_a) of samples was measured by electro-hygrometer Rotronic (Crawley, UK) after equilibrium was reached at 25 °C.
- Particle size distributions of samples were determined using sieves with mesh size ranging between 200 and 2000 μm.
- Bulk and tapped density was measured using an STAV 2003 Engelsmann model AG (Ludwigshafen, Germany).

2.3. Flow property measurement by shear cell test

Flow characteristics of the food powders were determined according to the Jenike (1964) shear tester. The tester was 95 mm in diameter and 50 mm in height. Food powder was removed from its packaging and loaded into an annular shear cell. The procedure used to measure the instantaneous flowfunction is recommended by the Standard Shear Technique and uses the Jenike shear cell (Warszawa, Poland).

Four yield loci and five points for each yield locus were obtained for all flowfunctions. To construct a yield locus the powder was critically consolidated under a known consolidating stress and the shear stresses required to cause the powder to fail were measured under four normal stresses, less than the consolidating stress, and at the consolidating stress. A yield locus is a plot of failure shear stress versus normal stress for a given consolidating stress. This was repeated for four different consolidating stresses to obtain four yield loci. Every point of the yield locus was repeated three times.

From each yield locus the following two quantities were estimated by two specific Mohr circles: unconfined yield strength (UYS) and the major consolidating stress (MCS). A flowfunction is a plot of UYS versus MCS. It shows the stress needed to make an arch collapse and make the material flow (Fitzpatrick et al., 2004; Fitzpatrick, Iqbal, et al., 2004; Iqbal & Fitzpatrick, 2006).

2.4. Compression test

Compression testing was done by ZWICK 1445 (Ulm, Germany). Powder was poured into a stainless-steel test cell (90 mm in diameter and 29 mm in depth). Powder excess was scraped off. The test cell was then mounted on the base plate of ZWICK Universal Testing Machine and the powder specimen was compressed with 34 N (compressive stress of 5.34 kPa) compression force at a crosshead speed of 1 mm/min. This level of compressive stress corresponds to compressive stress occurring within retailer packages. The force and the relaxation time curves were recorded by computer. Every measurement was repeated three times. Compression curves are plots which show the process of true strain ε dependency versus compressive stress σ. Relative strain ε_w was calculated from equation: