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Effect of water content on the flowability of hygroscopic powders

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ABSTRACT

Hygroscopic powders adsorb water from air humidity, increasing their cohesion and decreasing their flowability. Maltodextrin, pectin and starch powders were used to evaluate the correlation between flow factor and water content expressed both, as absolute moisture, and as water activity. Powder water content was adjusted through exposition to high relative humidity atmospheres. Maltodextrin and starch powders did not change their flowing behavior within the studied range, remaining easy-flow and cohesive powders respectively. Pectin powder, on the other hand, adsorbed water up to 12% (w/w), modifying its flowability from free-flow, to easy-flow, to cohesive powder. Powders flow factor changed as water content increased in all tested conditions. However, flow factor showed to be better correlated to water activity than to absolute moisture content. These results suggest water activity may be a better parameter to describe the effect of water content on powder flowability than absolute moisture.

1. Introduction

Handling of powders in the food and pharmaceutical industries represents an important challenge depending on their capacity to flow freely in a fluid-like fashion. Free-flowing powders are typically preferred since such capacity allows for easier continuous automated transport. Jenike (1964) described powders flow behavior using the flow factor, which correlates the stress required to consolidate a powder with the force needed to make it flow again (Eelkman, 1975). Flow factor values above 10 correspond to free-flow powders while values between 4 and 10 indicate easy-flow characteristics. Cohesive powders exhibit a flow factor between 2 and 4, and very cohesive non-flowing powders show a flow factor below 2. A more detailed description of concepts and quantification methods employed for the characterization of powder flowability can be found elsewhere (Juliano and Barbosa-Cánovas, 2010; van Ommen et al., 2012).

Most dry powders are free-flowing and their handling does not represent a technical problem. Wet or higher-moisture powders, on the other hand, will typically cause more transport and storage difficulties. Dry powders may adsorb water when exposed to high relative humidity environments, depending on their physical structure and chemical nature. Powders hygroscopicity is used to describe the powder ability to uptake water from ambient moisture. Callahan et al. (1982) and Murikipudi et al. (2013) proposed a hygroscopicity classification based on the rate and amount of water adsorbed by powders from air at a specific relative humidity (RH). Very hygroscopic powders can adsorb water when exposed to atmospheres of 50% RH or lower, and increase their moisture content more than 60% (w/w) when exposed to 90% RH conditions. Moderately hygroscopic and slightly hygroscopic powders adsorb water only when exposed to conditions above 60% and 80% RH, increasing their moisture content less than 60% and 40% (w/w) when exposed to 90% RH conditions, respectively. Finally, non-hygroscopic powders do not increase their moisture content in atmospheres below 90% RH, but can take up water up to 20% (w/w) under environmental conditions over 90% RH.

As a general principle, powders water content may always be considered as inversely correlated with its capacity to flow (Ortega-Rivas, 2011). However, the nature of this correlation must be further investigated. Teunou and Fitzpatrick (1999) studied the effect of environmental relative humidity over the flow factor of commercial

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powders. Powders flow functions showed a decrease in flowability when relative humidity increased, although low correlation coefficients between flow factor and relative humidity were found.

Absolute moisture and water activity are two parameters employed to describe water content in powders (Crouter and Briens, 2014; Peleg, 1977; Teunou and Fitzpatrick, 1999). Absolute moisture, on one hand, states the total amount of water in the powder matrix (grams of water per gram of dry solids), while water activity on the other hand provides information on how this water binds to the powder matrix. The relationship between absolute moisture content and powder flowability has been studied and reported since the 1960s (Callahan et al., 1982; Coelho and Harnby, 1978; Crouter and Briens, 2014; Li et al., 2016; Shenoy et al., 2015; Walker, 1967). The relationship between water activity and powder flowability however, has not been reported in technical literature until more recently (Hardy et al., 2002; Moreyra and Peleg, 1981; Ostrowska-Ligęza and Lenart, 2015). All published studies have shown a reduction in food powder flowability when moisture content or water activity increase. Nevertheless, it is important to consider that moisture content and water activity are not linearly correlated, but correlate nonlinearly at constant temperature following a sigmoidal shape known as water sorption isotherm (Al-Muhtaseb et al., 2002). This non-linear relationship between moisture content and water activity makes it possible for powder flowability to linearly correlate better with one of the two aforementioned parameters, demonstrating the superiority of such water content index as a means to characterize the influence of water on the flowability of powders. Therefore, the aim of this study was to characterize the effect of the water content expressed either as absolute moisture or as water activity on the flow factor of three hygroscopic powders: maltodextrin, starch and pectin.

2. Materials and methods

2.1. Powders selection

Three commercial food powders were selected based on their hygroscopic nature and wide use in food powdered formulations. Pectin was obtained from DuPont-Danisco (City of Mexico, Mexico), while maltodextrin and modified starch powders were purchased from CP-Ingredients (Jalisco, Mexico).

2.2. Water content adjustment

Powders with different water content were obtained by the accelerated microclimate method (Mathlouthi and Rogé, 2003) using pure water to maintain a high relative humidity inside the conditioning chamber. Two hundred grams of each powder were uniformly distributed in trays and placed 0, 24, 48, 72 and 120 h in the conditioning chamber for water content adjustment. After conditioning, samples were thoroughly mixed and immediately subjected to assay. Powder water activity was measured with a Labmaster AW (Novasina AG, Switzerland), while absolute moisture content was determined following AOAC 934.01 method (AOAC, 2010).

2.3. Flowability characterization

Flow function and bulk density were obtained using the Powder Flow Tester (PFT; Brookfield, Middleboro, Massachusetts, USA). In addition, using flow function data, cohesion was estimated by linear regression analysis. All flowing parameters were obtained using 5 consolidation levels: 0.289, 0.584, 1.180, 2.385 and 4.819 kPa with 3 over-consolidation stresses using a 6 inch 304 stainless steel vane lid and the 263 cc volume shear cell. All tests were based on annular procedures and Jenike's shear test techniques. PFT data was collected running the standard procedure with the Powder Flow Pro V1.3 software.

2.4. Hygroscopicity classification

Hygroscopicity classification was conducted according to Callahan et al. (1982) methodology (conventional method) with some modifications. One gram of each powder was conditioned at 86% RH for 1 week, recording the initial and final weight. Chamber relative humidity was set using a saturated potassium chloride solution. Weight gain was employed to classify powders according to the hygroscopicity classification scale previously described.

2.5. Statistical analysis

A one-way completely randomized design was employed to study the effect of absolute moisture and water activity on powders flow factor. Each test was carried out at least by duplicate. An analysis of variance and multiple comparison Tukey's test were conducted to identify significant differences at $\alpha = 0.05$ significance level. Linear regression analyses were performed to evaluate the correlation between powder flow factor and water activity or absolute moisture. All statistical analyses were carried out using Minitab 16 (Minitab Inc., State College, PA, USA).

3. Results and discussion

3.1. Characterization of unconditioned powders

Unconditioned powders characterization is showed in Table 1. Pectin showed to be a free flowing powder while maltodextrin and starch were easy flowing and cohesive powders respectively. The observed flow capacity of maltodextrin and starch was in agreement with previous studies. Fitzpatrick et al. (2004a) classified maltodextrin as an easy flowing powder, with a flow factor of 4.9 at 4.3% absolute moisture (w/w), and corn starch as a cohesive powder with a flow factor of 2.1 at 10% absolute moisture (w/w). Tan and Newton (1990) also classified two starch powders as cohesive, having flow factors of 2.2 and 3.5 at absolute moisture levels of 9.6% and 9.7% and average particle size of 11 and 17 μm, respectively. These studies stablish that starch powders are generally cohesive. Cohesive flow behavior of starch at low water content is typically attributed to interlocking of porous and irregularly shaped starch particles (Saad et al., 2011). Water adsorption by starch particles at higher water content may cause swelling, decreasing particles interlocking (Wang et al., 2014). Nevertheless, concurrent liquid-bridges formation increases particles interactions, contributing to an increase in cohesiveness.

Modified starch powder showed lower moisture content and higher water activity than pectin powder in this study. Pectin and modified starch cohesion values were not significantly different; however, pectin flowability was significantly higher than that of starch. This observation seems contradictory, since powders flowability is generally associated to their cohesiveness (Crouter and Briens, 2014). Typically, powder flowability decreases as cohesion increases, since cohesion is the result of the attraction forces between particles, liquid bridges forces, and particles interlocking forces (Hartley et al., 1985; Peleg, 1977). In this case, the observed differences in the flowing capacity of modified starch and pectin with similar cohesion values could be due to their different composition and the way in which their components bind water. Polarity of surface structural compounds defines how much water may be adsorbed and bound into the powder matrix (Rennie et al., 1999) and also define the rate of water adsorption (Sandler et al.,

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