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Influence of alternative drying aids on water sorption of spray dried mango mix powders: A thermodynamic approach

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ABSTRACT

Mango pulp mixed with drying aids (maltodextrin and skimmed milk) was spray dried to obtain three powder formulations. The water sorption behavior of these mango mix formulations was determined at temperatures of 20, 30, 40 and 50 °C in water activity ranging between 0.059 and 0.907. The Guggenheim, Anderson and De Boer (GAB) model was applied to modeling the adsorption isotherms of mango mix powders, resulting in statistical values of mean relative error ($MRE \leq 5.14\%$). Differential and integral thermodynamic properties related to water sorption for the mango powders were determined by the analytical derivation of the water activity with respect to temperature based on the GAB model fitting. The differential thermodynamic properties indicated a decrease in the water sorption energy with increasing water content and the negative values of the Gibbs free energy revealed that the sorption process was spontaneous for the three powder formulations. In spite of the formulation containing skimmed milk have shown the higher monolayer water contents, the minimal integral entropy zone observed at similar values of water activity for the three mango mix powders indicated that all of them could be safely stored at the same relative humidity condition.

Keywords: Spray drying; Modeling; Thermodynamic properties; Carrier agents; Sorption isotherms

1. Introduction

Fresh fruits are important components of human diet, occupying the second place in the food pyramid. For this reason, producing convenient and healthy food products similar to the fresh ones and preserving their own physicochemical properties with increased shelf life, without reducing their sensorial and nutritional properties, has been the focus of numerous studies for many years.

Among the tropical fruits, the mango (*Mangifera indica*) is one of the most appreciated for consumption, as well as a major object of research studies (Bon et al., 2010; Rangel-Marrón et al., 2011). Surrounding the stone containing the seed, the fruit presents an attractive yellow or orange flesh with variable amounts of fibers. Mango pulp contains about 14% of total sugars, from which sucrose is the main constituent, vitamin C (37 mg 100 g^{-1}), minerals such as riboflavin, niacin, calcium, phosphorus, iron and, likewise, a considerable quantity of carotenes (Vaughan and Geissler, 2009; Rangel-Marrón et al., 2011; Bello-Pérez et al., 2005). The production of mango ranks second among the tropical fruits, but in terms of consumption, mango ranks first worldwide derived from fresh consumption. The world production is around of 39 millions of tons with India, China, Pakistan, Mexico and

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Brazil being the greater producers (FAOSTAT, 2010). Due to its good acceptability and high perishability, the development and characterization of dehydrated products based on mango fruit, such as spray dried mango powders, would be interesting to be used by the food industry as functional ingredients or in the formulation of new products (Caparino et al., 2012).

Powdered juices might constitute good alternatives to convenient and healthy food products or ingredients to formulated foods. Nevertheless, drying and storage of powdered fruit juices present technical difficulties due to their hygroscopic and thermoplastic behavior at high temperature and/or humidity, a characteristic associated to powder composition (Kudra and Mujumdar, 2009). When the low molar mass compounds, which are present in high amounts in fruit juices or pulps, undergo a rapid water removal, such as during spray drying, the resulting solid matrix may be in an amorphous metastable state. This amorphous matrix is very susceptible to water plasticization followed by glass transition related changes, including stickiness, caking, and collapse, as well as color changes (Mrad et al., 2012; Telis and Martínez-Navarrete, 2012).

A simple and practical strategy to improve drying of such products has been to add high molar mass additives, such as starches and maltodextrins, in order to increase the glass transition temperature (T_g) of the powdered mixture (Fabra et al., 2011). Maltodextrins result from acid and/or enzymatic hydrolysis of starch, but in a lower extent than required to produce starch syrups. Among the wide choice of commercially available maltodextrins, choosing the appropriate one for these applications is a matter of compromise between its properties in solution (before the process) and its properties at the glassy state (after the process) (Avaltroni et al., 2004).

Skimmed milk presents non-stick properties similar to other commonly used additives (Adhikari et al., 2004). During spray drying of maltodextrin and skimmed milk, it has been shown that both materials had the same rates of cohesion and adhesion, however, maltodextrin (DE 18) showed a lower deposition rate than milk, what was associated with its higher glass transition temperature compared to skimmed milk (Langrish et al., 2007). Considering that skimmed milk is highly available in most of countries, it has been suggested as an effective and cheap alternative for regular additives (Catelam et al., 2011). In addition, powdered milk and dried fruit pulps are usually mixed together in order to formulate blended instant powders for nutritive beverage preparation.

The structure and composition of a food material play a key role on its sorption behavior and experimental assays are mandatory to elucidate this phenomenon in complex systems such as food, providing important information on the hygroscopic state of the amorphous microstructure in fruit powders (Al-Muhtaseb et al., 2004). Knowledge of physicochemical nature of water bounded to the solid matrix is fundamental to understand the effect of water content and storage conditions on food stability. Certain thermodynamic parameters can be estimated from the sorption isotherms and this information is useful in understanding the physicochemical binding of water when the product is subjected to different temperatures and relative humidity conditions (Azuara and Beristain, 2006). Properties such as enthalpy, entropy and Gibbs free energy are useful to explain reactions and phenomena at molecular level in materials. These properties represent the amount of energy, the order or excited state and the chemical equilibrium of the water molecules inside the material, respectively (Brovchenko and Oleinikova, 2008). Changes in some thermodynamic properties with respect to water content and temperature can provide a good description of the water sorption mechanisms and can be used to estimate transitional points between them (Karel, 1975). Furthermore, the hydrophobic and hydrophilic interactions between water and other molecules can be explained from the linear relationship of the entropic and enthalpic mechanisms and the pore-water interaction (Azuara and Beristain, 2006; Labuza et al., 1985).

Based on these considerations, the objective of this work was to study the effect of different drying aids (maltodextrin and skimmed milk powder) on the thermodynamic properties related to water sorption for mango mix powders.

2. Materials and methods

2.1. Raw material

Mango fruits (*Mangifera indica* cv. Tommy Atkins) were obtained from a local market in São José do Rio Preto (SP, Brazil) and stored at 7 °C prior the use. The pulp separated from the skin and from the seed was processed in a food blender until a homogeneous mixture had been obtained.

2.2. Preparation of powder samples

The mango pulp (14.2 kg kg^{-1}, dry basis of solids) was added with two different additives: maltodextrin with $17.0 \leq DE \leq 19.9$ (MOR-REX® 1920, Corn Products, Brazil) and skimmed milk (commercial UHT skimmed milk, Batavo®, Brazil). Two formulations were prepared using mango pulp (P) and maltodextrin (M) in ratios of 1:8 and 3:6 (dry mass basis) and, a third formulation was prepared using mango pulp, maltodextrin and skimmed milk (SM) in a ratio of 1:4:4 (dry mass basis). The formulations were mixed using a mechanical stirrer (model TURRATEC TE-102, Tecnal, Brazil) at 500 rpm and 25 °C. After mixing, the formulations were dehydrated in a laboratory scale spray drying (model B-290, Büchi, Switzerland) at the following conditions: air flow rate, 152.74 mL s^{-1}; feed rate; 0.05 mL s^{-1}; aspiration rate, 85%; and air-drying temperature 170 °C. Approximate 200 g of powder were obtained for each dried sample, which were coded as: P–M (1:8) and P–M (3:6) for the mix powders of mango pulp and maltodextrin and P–M–SM (1:4:4) for the mix powder of mango pulp, maltodextrin and skimmed milk.

2.3. Determination of sorption isotherms

The equilibrium water contents of the mango mix powders were determined using the static gravimetric method (Jowitt et al., 1987) at temperatures of 20, 30, 40, and 50 °C. The experimental setup consisted of ten hermetic glass jars containing different saturated salt solutions, each one allowing a corresponding relative humidity (RH) in the range of 5.9–90.7% depending on the solution used. Each jar was filled to a depth of 1.5 cm with the salt solution. For each measurement, three replicates of about 1 g of sample were placed into small plastic containers, which in turn were placed on a support inside each jar in order to avoid contact with the salt solution. The jars were subsequently placed in a temperature-controlled chamber (BOD, Model TE-391, TECNAL, Brazil). The sample weights were monitored until the variation in the dry-basis water content did not exceed 0.1% (time elapsed from 4 to 5 weeks), when it was assumed that the equilibrium had been reached, assuring that the water activity of each sample