Defining High and Low Spray Drying Temperatures for *Aloe vera* Gel

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Abbreviations

ANOVA	Analysis of variance
a_w	Water activity
C_G	Energy constant relating to the temperature
GAB	Guggenheim-Anderson-De Boer equation
K_G	Energy constant relating to the temperature
μ	Media of the analyzed continuous variable
M	Moisture content of the powder
M_o	Theoretical water content of the monolayer
T_1	Input temperatures
T_2	Output temperatures
T_g	Glass transition temperature
T_{gm}	Mix glass transition temperature
T_{gs}	Solids glass transition temperature
T_{gw}	Water glass transition temperature

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X_m Water weight fraction
X_s Solids weight fraction
σ Standard deviation of the analyzed continuous variable

1 Introduction

Spray drying is widely used in the food industry to obtain products in the form of powder (Masters 1991; Filková and Mujumdar 1999; Nijdam and Langrish 2005; Roustapour et al. 2006; León et al. 2010). Three types of modes of contact between drying air and the food product can be found: parallel (co-current), counter-current, or mixed (fountain). The latter is a combination of parallel and counter current flow patterns, which implies that the already dry material comes into contact with drops being sprayed, favoring the formation of agglomerates. In turn, the formation of agglomerates raises the rehydration capacity of the final product (Masters 1991; Vega et al. 2001; Peighambardoust et al. 2011). Although spray drying is a common method used for drying thermolabile materials, there are few reports about the dehydrating conditions used for *Aloe vera* industrial processing. This plant is widely used in the pharmaceutical, cosmetological, and food areas because of the beneficial effects it provides as a functional ingredient in food and cosmetic products (Simal et al. 2000). However, it has been reported that when gel obtained from the *Aloe vera* leaf is subjected to thermal processing, changes in its components and functional properties, such as wettability, water retention, and oil adsorption capacity, among others, can occur (Eshun and He 2004; García et al. 2010). Aloe gel contains 98.5 % water, and the remaining solid material consists of polysaccharides, fat, and water-soluble vitamins, minerals, enzymes, phenolic compounds, and organic acids (Bozzi et al. 2007; Eshun and He 2004; Hamman 2008). Several studies have focused on assessing the physical, chemical and functional changes caused by *Aloe vera* gel processing conditions, especially during dehydration through convective drying (Simal et al. 2000; Femenia et al. 2003; Miranda et al. 2009; García et al. 2010; Gulia et al. 2010). However, to date there is limited data regarding the effect that spray drying temperature has on the physical, calorimetric, and functional characteristics of *Aloe vera*. Therefore, the objective of this study was to evaluate the effect of spray drying temperatures on obtaining *Aloe vera* gel in powder form.

2 Materials and Methods

2.1 Obtaining Aloe vera *Powder*

Aloe vera gel was obtained from the "Flor de *Aloe*" Company (Puebla, México), which was filtered for processing in a Mobile Minor 2000 spray dryer (Gea-Niro, Dinamarca) equipped with a dual fluid nozzle in a source-type arrangement and without any addition of drying aid. The inlet (T_1) and outlet (T_2) drying-air temperatures used were 220, 225, and 250 °C and 70, 80, and 90 °C, respectively. The feed stream varied between 1.12 and 1.85 L/h, depending on the desired outlet air temperature when the pressure of the air spray was 1.53 kg cm^{-2}. Powder samples were gathered at the cyclone base and stored in sealed containers for further analysis, which was performed three times in every case.

2.2 Powder Analysis

The moisture content of *Aloe vera* gel without processing was determined using a thermo gravimetric method, by means of a thermo balance MB 300 (Brainweigh, USA). Moisture content of the powder (M) was determined using the vacuum drying oven method according to 920.151 (AOAC 1997).

Water activity (a_w) was determined using Aqualab 4TE equipment (Decagon Devices, USA) from 1 g (0.035 oz) of the powder while maintaining a temperature of 24.5 ± 0.1 °C (Fang and Bhandari 2011).

2.3 Guggenheim–Anderson–De Boer Equation (GAB)

In order to understand the adsorption process of water by the amorphous powders, the GAB model (van den Berg and Bruins 1981) was applied to the experimental data using the linearized form expressed by Eq. (1):

$$\frac{a_w}{M} = \frac{1}{M_o C_G K_G} + \frac{C_{G^{-2}}}{M_o C_G} a_w + \frac{K_G(1 - C_G)}{M_o C_G} a_{w^2} \tag{1}$$

where M is the moisture content (g of water/100 g of dry solid), a_w is the water activity, M_o is the theoretical water content of the monolayer, and C_G and K_G are energy constants relating to the temperature.

2.4 Glass Transition Temperature (**T**$_g$)

Glass transition temperature of the powders was determined by a differential scanning calorimeter (Diamond, Perkin Elmer, USA) using 15 mg of sample powder in 20 μL sealed aluminum capsules and applying a temperature sweep from −20 to 120 °C and a heating rate of 20 °C/min (Ozmen and Langrish 2002). In order to understand the relationship between the glass transition temperature with different solid and moisture content (M), the Gordon and Taylor equation was applied (Gordon and Taylor 1952), as expressed by Eq. (2):

$$T_{\mathrm{gm}} = \frac{X_{\mathrm{s}} T_{\mathrm{gs}} + k X_{\mathrm{w}} T_{\mathrm{gw}}}{X_{\mathrm{s}} + k X_{\mathrm{w}}} \tag{2}$$

where T_{gm}, T_{gs}, and T_{gw} are the mix, solids, and water glass transition temperatures, respectively, expressed in (°C); X_{s} and X_{m} are the solids and water weight fractions, respectively; and k is the Gordon and Taylor constant, which is related to the level of interaction between the system components. The model parameters (k and T_{gs}) of Eq. (2) were estimated using a nonlinear regression analysis where T_{gw} was −135 °C (Sablani et al. 2007; Welti-Chanes et al. 1999).

2.5 Statistical Analysis

The statistical significance of data was evaluated using the analysis of variance (ANOVA) analysis with $\alpha = 0.05$. The statistical analysis was performed using the statistical program MINITAB, version 15 (Minitab, Inc, USA).

To verify the existence of two or more groups and mathematically differentiating between them, the normal distribution density function was used. Normal distribution is defined as a continuous variable distribution that is specified by two parameters: mean and standard deviation (Eq. 3):

$$f(x) = \frac{1}{\propto \sqrt{2\pi}} \mathrm{e}^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \tag{3}$$

where μ is the mean and σ is the standard deviation of the analyzed continuous variable. Densities were obtained for each of the relationships discussed: moisture content, water activity, and glass transition-moisture content.

3 Results and Discussion

3.1 Moisture Content (M) and Water Activity (a_w)

M (kg of water/kg of dry solid) of gel powder showed values between 0.01 and 0.03 (kg of water/kg dry solids), with no significant difference found at a level of $\alpha = 0.05$ for any of the obtained products under the different drying-air temperatures. These values are similar to those previously obtained for various powder products at different drying conditions (mucilage nopal, nopal juice, and acai pulp) (Tono et al. 2008; León et al. 2010). a_{w} ranged from 0.18 to 0.30, without a clear relationship between inlet/outlet drying-air temperature effect and a_{w}. Similar values of a_{w} have been reported for other powder products, such as watermelon (0.20–0.29) (Quek et al. 2007), milk (0.2–0.6) (Laroche et al. 2005), and bayberry

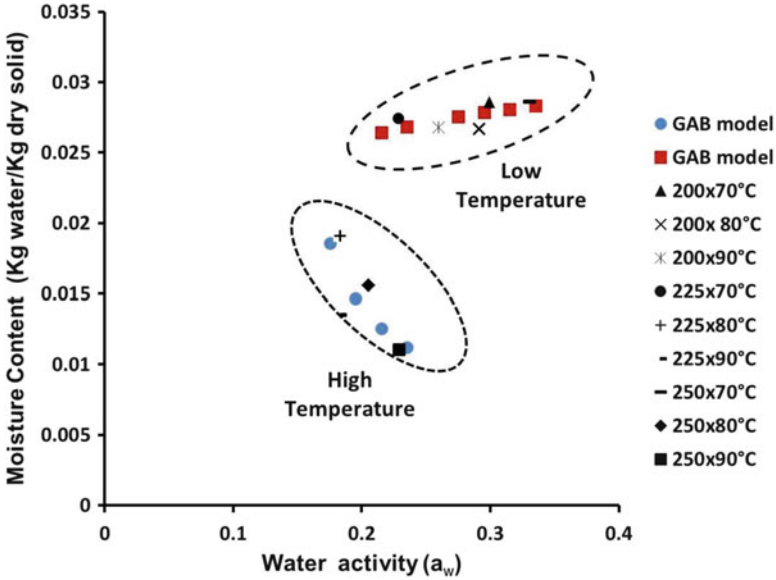

Fig. 1 Moisture content (*M*) and water activity (a_w) in relation to samples obtained at different inlet air temperatures, and moisture adsorption behavior (GAB model) of *Aloe* powders obtained by spray drying

(0.1–0.3) (Fang and Bhandari 2011). For all *Aloe vera* gel powder samples, the existing relation between *M* and a_w is observed in Fig. 1, and the existence of two different data groups is also identified in this figure. In the first group, which was called the low temperature group, samples were assessed using inlet/outlet temperatures of 200/70, 200/80, 200/90, 225/70, and 250/70 °C. These conditions correspond to all cases in which the lower inlet and three outlet temperatures were used, and also to the 225 and 250 °C temperature conditions, in which the lower outlet temperature was used. The second group, denoted as the high temperature group, had the samples with the lowest values of *M* and a_w, and corresponded to the highest inlet/outlet drying-air temperatures (225/80, 225/90, 250/80, and 250/90 °C). When inlet temperatures of 200 °C and any outlet temperature were used, the *M* and a_w values of the products were higher; at 225 and 250 °C inlet temperatures and 70 °C outlet temperature, materials were located within the low temperature drying groups. All conditions were grouped as high temperature.

3.2 *Analysis of the GAB Equation Adjustment*

Applying the GAB model to *M* and a_w, the results showed that they can also be grouped into the low and the high temperature groups (Fig. 1). In the first case, it is possible that drying temperatures causes minor heat damage to the material;

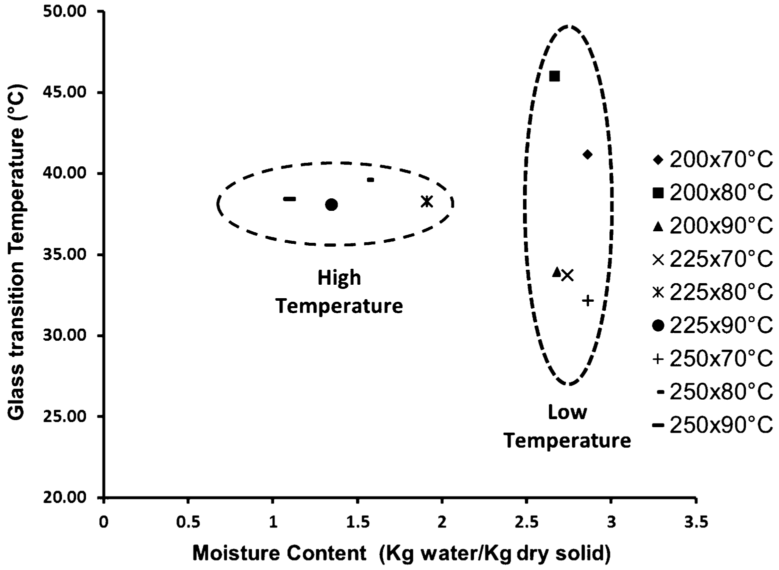

Fig. 2 Relationship between glass transition temperature (T_g) and moisture content (M) for *Aloe* gel powders obtained from different drying conditions

therefore, they could belong to the same isotherm, which may indicate that under these drying conditions, the original chemical composition of the material does not change significantly. The opposite could occur in the high temperature group, where the material may present different characteristics from those obtained at low temperatures. Therefore, they would be associated with different hygroscopic properties.

3.3 Glass Transition Temperature (T_g)

Thermograms of product obtained under different drying conditions showed that T_g ranged from 33 to 45 °C. These values match those reported for other similar material, such as maltodextrins (10–20 DE), where T_g was reported to be in the range of 45.4–54.7 °C (Cai and Corke 2000). In addition, whole and pulp strawberry had a T_g of 30 °C and a moisture content of 1.4 % (Moraga et al. 2004). Foster et al. (2006) reported that for lactose–glucose and lactose–fructose mixtures (both with $a_w = 0.23$) a T_g of 25 °C and 30 °C, respectively, and León et al. (2010) reported that spray dried nopal mucilage powder had a T_g of 45 °C with 7.2 % moisture. In the literature, there are reports of different glass transition temperatures for different carbohydrates, such as mannose (31 °C), glucose (31 °C), galactose (32 °C), and sucrose (62 °C) (Bhandari and Howes 1999). Figure 2 shows the

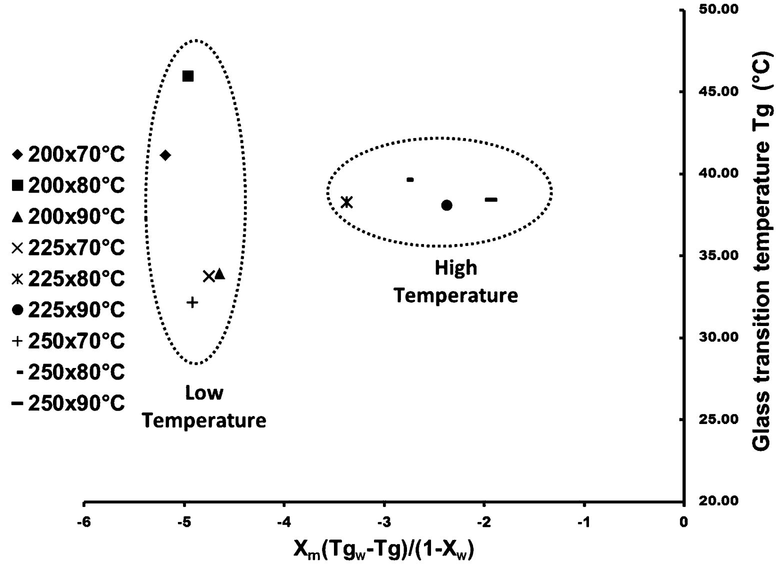

Fig. 3 Glass transition temperature (T_g) variation of *Aloe* gel powder obtained by spray drying according to Gordon and Taylor model

relationship of T_g and M for the different powders obtained; even though a direct relationship between these properties could not be observed, it was possible to classify all obtained powders into groups identified. It has been suggested that *Aloe* gel powder remains in a vitreous state at room temperature, regardless of the drying-air temperature. Moreover, at higher temperatures and moisture levels, the plasticization effect can increases the loss of powder quality. The results experimentally obtained (M, a_w, and T_g) were analyzed using the Gordon and Taylor model (Eq. 2) to determine if exists any correlation between experimental values of water activity and glass transition. The results for all powders obtained at the different drying-air temperatures showed relatively low values of a_w (0.18–0.33). The interval of water activity at which the samples are located is a narrow section of the values of water activity (0.1–0.9) which should cover the samples, as indicated in the analysis of the model of Gordon and Taylor. In this case, separation of the samples in the high and low temperature groups was also verified (Fig. 3).

4 Conclusions

In this study, the *Aloe vera* gel (without drying adjuvant) can be spray dried using an inlet drying-air temperature greater than or equal to 200 °C and the outlet drying-air temperatures from 70 to 90 °C, in a fountain type arrangement. The drying-air temperatures can be classified into high or low drying temperature groups according to changes in the values of M, a_w, and T_g properties of the powders obtained, and assessed through the normal distribution density function. The GAB equation and the Gordon–Taylor model are useful tools to identify the effects of the drying-air temperature on the physical properties of dehydrated material, as well as to categorize if a spray drying temperature is low or high.

However, it is important evaluate the prime thermolabile components of the gel, as well as the chemical changes observed, to achieve a better understanding of the relationship of these changes with the hygroscopic properties and transition phases of the powder product.

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