THE EFFECT OF SPRAY DRYING PROCESSING CONDITIONS ON PHYSICAL PROPERTIES OF SPRAY DRIED MALTODEXTRIN

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Abstract

Maltodextrins have wide applications particularly in the food industry. They have many functionalities including usage as wall material, dispersing aid, flavor carrier, bulking agent, viscosifier or fat re-placer, and they exhibit only a slightly sweet taste. Maltodextrin was subjected to spray drying to determine the effect of spray drying conditions on moisture content, particle properties (particle size distribution and particle density) and bulk properties (bulk and tapped densities and porosity) of the powder product. Experiments have been performed in a lab scafle spray-dryer (BüchiLabortechnik AG, Flawil, Switzerland) using a full-factorial design to provide data and correlations that predict the powder properties as a function of the main operational variables of the spray-dryer. The inlet (140 and 200 °C) and feed temperatures (10 and 50 °C), feed flow rate (2.1×10^{-4} and 9.6×10^{-4} kg s^{-1}) and atomizing air flow (1.3×10^{-4} and 1.9×10^{-4} m^3 s^{-1}) were investigated as spray drying process variables. The effect of spray drying conditions on physical properties of powders was expressed with three dimensional response surface and perturbation graphs. Perturbation graphs revealed that atomizing air flow and inlet air temperature had more effect than feed temperature and feed flow rate on the physical properties of maltodextrin powder. The results showed that the Sauter mean diameter ($D_{3,2}$) was between 3.503 and 6.045 µm for maltodextrin powders.

Keywords: maltodextrin, spray drying, particle and bulk properties, particle size distribution.

Introduction

Spray drying is a well-established and widely used method for transforming a wide range of liquid food products into powder form. Spray-dried powders can be stored at ambient temperature for prolonged periods without compromising the powder stability. They are also cheaper to transport and easier to handle in manufacturing plants (Koç et al., 2010; Koç et al., 2011). However, caking or stickiness as one of the major degradation problems hindered the development of powders (Adhikari et al., 2007). The problem is mainly due to the existence of low molecular weight sugars with low glass transition temperatures. To produce food powders, using maltodextrins as a drying carrier is a popular method nowadays (Bhandari et al., 1997). Maltodextrin can significantly increase the glass transition temperature and reduce the hygroscopicity of dried products (Goula, Adamopoulos, 2008). Maltodextrin, a common encapsulating material used in the food industry, is made by the hydrolysis of starch, and comes in the form of a white powder and has a sweet taste. Maltodextrins have particularly wide applications in the food industry especially in spray drying. They have many functionalities including usage as wall material, dispersing aid, flavor carrier and bulking agent. They are mainly used in materials that are difficult to dry -such as fruit juices, flavorings, and sweeteners- and to reduce stickiness, thereby improving the product stability (Bhandari et al., 1993; Bhandari et al., 1997; Roos, Karel, 1991). For this reason, spray drying conditions and physical properties of maltodextrin should be determined.

Physical properties of food powders including the particle shape, density and porosity, surface characteristics, diameter, and size (Kurozawa et al., 2009) can be affected by the spray drying temperatures and the type of atomizer, that are important in the storage, handling and final application of powder product (e.g. particle and bulk properties).

Particle properties are directly related to physical properties of powder food products (Schubert, 1987). It is known that complex changes in the particles properties (size, shape, density and appearance) of droplets occur during spray drying and that the protection of these properties is related to the porosity and integrity of the microcapsules. With respect to morphology, the particles produced by spray drying generally show a smooth surface and are spherical in shape, have lowest surface-to-volume ratio (aroma retention), highest bulk densities (best packing) and best flowability (Kurozawaet et al., 2009).

One of the most important physical parameters of powders with regard to handling is particle size. Particle size can influence flow out of storage bins, the blending of different components, compaction, and the segregation of a mixture, in which smaller particles stay distributed on the bottom and larger particles on top. In addition, these properties significantly influence the essential properties of food products such as smell, texture, and appearance. As particle size decreases, the increase in the particle surface area causes higher affinity with moisture and higher ability to agglomerate during the drying process. The knowledge of food density is of fundamental use for material properties studies and for industrial processes in adjusting storage, processing, packaging, and distribution conditions. Bulk density includes the volumes of the solid and liquid materials and all pores and is generally used to characterize a final product obtained by drying (Kurozawa et al., 2009).

In this study, it was aimed to determine the influence of spray drying process, in terms of inlet air and feed temperatures, feed flow rate and atomizing air flow on moisture content, water activity, particle properties (particle size distribution and particle density) and bulk properties (bulk and tapped densities, porosity, flowability) of maltodextrin.

Materials and Methods

Maltodextrin (DE=8), used as the test material was supplied from Çağdaş Kimya, Turkey. Maltodextrin was dissolved in the distilled water and the solution containing 25% maltodextrin was used in the experiments.

Spray Drying

Experiments were conducted in a lab scale spray dryer (BüchiLabortechnik AG, Flawil, Switzerland). Maltodextrin solution was atomized from 0.7 mm nozzle into vertical, co-current drying chamber, 0.16 m diameter and 0.5 m height, using a full-factorial design to provide data and correlations that predict the powder properties as a function of the main operational variables of the spray-dryer. The inlet air (T_{inlet}) (140 and 200 °C) and feed (T_{feed}) (10 and 50 °C) temperatures, feed flow rate (V_{feed}) (2.1E-04 and 9.6E-04 kg s^{-1}) and atomizing air flow ($V_{air\text{-}flow}$) (1,3 E-0.4 and 1.9E-0.4 m^3 s^{-1}) were investigated as spray drying process variables.

Moisture Content

The moisture content (MC) of maltodextrin was measured with a halogen moisture analyzer (Ohaus MB45, Switzerland) which was correlated well with the oven method, drying at 110 °C for 2 h.

Particle Properties

Particle size distribution: The particle size distribution of the maltodextrin was measured using a laser light diffraction particle size analyzer (MasterSizer model S 2000, Malvern Instruments Ltd., Worcestershire, U.K.) in which a small quantity of the powder was dispersed in water and the particle distribution was monitored during five successive trials. The particle size was expressed as mean area size $D_{3,2}$ (Sauter mean diameter), and was calculated as follows:

$$d_{3,2} = \frac{\sum_{i}^{N} n_i d_i^3}{\sum_{i}^{N} n_i d_i^2} \tag{1}$$

Where n_i is the number of particles of diameter d_i. The particle size distribution of the powder was measured as the span which is defined as;

$$span = \frac{d_{90} - d_{10}}{d_{50}} \tag{2}$$

Where d_{90}, d_{10}, and d_{50} are the equivalent volume diameters at 90%, 10%, and 50% cumulative volume, respectively.

Particle density: Particle density (ρ_p) of the powder samples was analyzed according to a study by Barbosa-Cánovas et al. (2005). The liquid (petroleum ether) pycnometry was used to determine particle density depending on the volume of pycnometer bottle used.

Bulk Properties

Bulk and tapped densities: The bulk density (ρ_b) of the maltodextrin was determined by measuring the weight of the powder and the corresponding volume. Approximately 20 g of powder sample was placed in a 100 mL graduated cylinder. The bulk density was calculated by dividing the mass of the powder by the volume occupied in the cylinder. For the tapped density (ρ_t), the cylinder was tapped vigorously by hand until no further change in volume occurred (Jinapong et al., 2008).

Porosity: Porosity (ε) of the powder samples was calculated using the relationship between the tapped (ρ_t) and particle (ρ_p) densities of the powders as shown below (Jinapong et al., 2008):

$$\varepsilon = \frac{(\rho_p - \rho_t)}{\rho_t} \times 100 \tag{3}$$

Statistical Analysis

All samples were analyzed in triplicate. The analysis of variance (ANOVA) at a confidence level of 95% was performed. All the results that were obtained were analyzed using Design Expert–version 7.0 software (Statease Inc., MI, USA).

Results and Discussion

$D_{3,2}$ (Sauter mean diameter) and span values of maltodextrin with respect to the inlet air and feed temperatures, feed flow rate and atomizing air flow are given in Table 1.

Table 1

Sauter mean diameter and span values of spray dried maltodextrin under 16 different experimental spray drying conditions

No	T_{feed}, °C	T_{inlet}, °C	V_{feed}, kg s^{-1}	$V_{air\text{-}flow}$, m^3 s^{-1}	$D_{3,2}$, µm	Span
1	10	140	2.1E-04	1.3 E-0.4	4.720	2.841
2	10	200	2.1E-04	1.3 E-0.4	4.644	2.119
3	50	140	2.1E-04	1.3 E-0.4	5.158	2.489
4	50	200	2.1E-04	1.3 E-0.4	4.691	1.906
5	10	140	9.6E-04	1.3 E-0.4	5.797	3.439
6	10	200	9.6E-04	1.3 E-0.4	4.019	1.768
7	50	140	9.6E-04	1.3 E-0.4	5.029	2.640
8	50	200	9.6E-04	1.3 E-0.4	6.045	3.022
9	10	140	2.1E-04	1.9E-0.4	3.815	1.860
10	10	200	2.1E-04	1.9E-0.4	3.919	1.642
11	50	140	2.1E-04	1.9E-0.4	4.184	1.954
12	50	200	2.1E-04	1.9E-0.4	3.904	1.905
13	10	140	9.6E-04	1.9E-0.4	4.006	2.279
14	10	200	9.6E-04	1.9E-0.4	3.503	1.997
15	50	140	9.6E-04	1.9E-0.4	5.586	3.653
16	50	200	9.6E-04	1.9E-0.4	4.003	2.058

Spray-dried products are usually nonhomogeneous. For nonhomogeneous systems, with particle size distribution, the voids between big particles are filled with smaller particles, which cause an increase of the bulk density (Schubert, 1987). The Sauter mean diameter ($D_{3,2}$) of a sphere, which gives an indication of the diameter corresponding to the average particle volume of the particle size distribution, and the span values varied between 1.642 and 3.653. The span-value expressing the width of the size distribution was also in the same order of magnitude. The particle size distribution of spray dried maltodextrin in 16 different experiments was shown in Figure 1-a and Figure 1-b. It can be seen that spray dried maltodextrin had a narrower particle size range with a relatively uniform distribution. The particle size distribution showed that all samples ranged from 3.503 and 6.045 µm. These results show that spray drying does not produce large particles. The mean particle size of a material may greatly influence its reactivity and the quality of the end product (Baranauskiene et al., 2006). Perturbation plots (Figure 2) showed that the Sauter mean diameter ($D_{3,2}$) of the maltodextrin powder was significantly affected by the atomizing air flow and inlet air temperature.

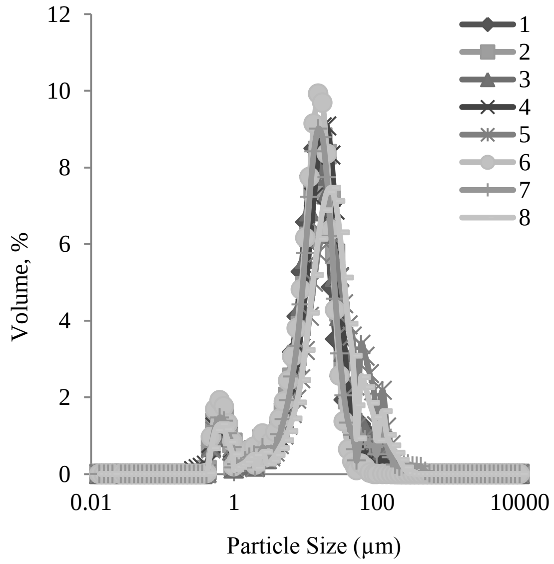

Figure 1-a. Particle size distribution of spray dried maltodextrin under 16 different experimental spray drying conditions (first 8 experiments)

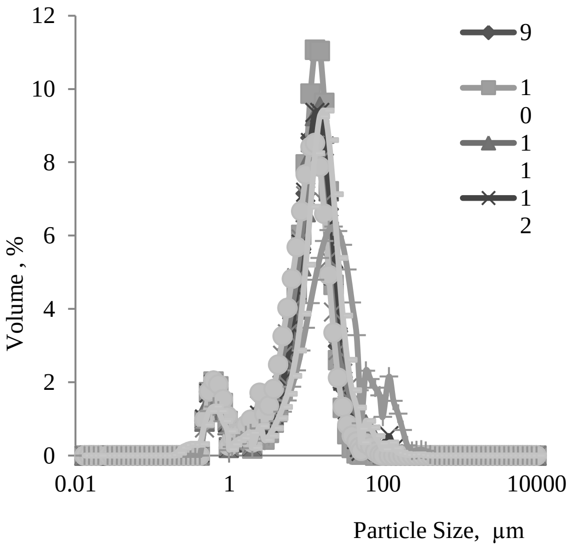

Figure 1-b. Particle size distribution of spray dried maltodextrin under 16 different experimental spray drying conditions (last 8 experiments)

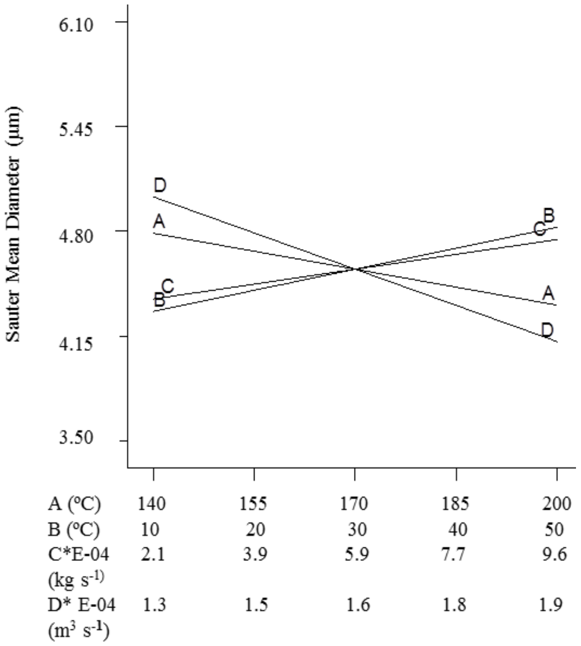

Figure 2. Perturbation plot of Sauter mean diameter ($D_{3,2}$)

A – Inlet air temperature, B – Feed temperature, C – Feed flow rate, D – Atomizing air flow

Table 2

Bulk and particle properties and moisture content of spray dried maltodextrin under 16 different experimental spray drying conditions

No	MC, %, wb	ρ_b, kg m^{-3}	ρ_t, kg m^{-3}	ρ_p, kg m^{-3}	ε
1	5.857	287.9	510.5	1094	53.34
2	4.863	253.5	426.8	924.9	53.86
3	5.477	293.1	439.7	1088	59.57
4	4.600	262.6	409.9	1180	64.27
5	8.880	329.7	572.9	1061	45.98
6	4.267	254.0	402.4	1110	63.73
7	6.353	299.4	455.6	1304	65.05
8	4.633	331.6	538.9	1190	54.70
9	4.300	279.0	484.3	1034	53.14
10	3.813	245.2	417.6	993.8	57.98
11	11.13	297.8	489.5	1165	57.97
12	6.750	306.9	455.5	1077	56.72
13	6.743	313.0	536.5	1127	52.39
14	6.263	263.0	445.6	1089	59.09
15	10.91	349.1	518.4	1263	58.97
16	6.097	302.7	489.3	1057	53.72

The moisture content (%, wet basis), bulk and particle properties of spray dried maltodextrin obtained at different experimental spray drying conditions is presented in Table 2.

Moisture content values varied between 3.81 and 11.13%, wet basis. Maximum moisture content (11.13%, wb) value was recorded at inlet air temperature of 140 °C, feed temperature of 50 °C, feed flow rate 2.1E-04 kg s^{-1} and atomizing air flow 1.9E-0.4 m^3 s^{-1} (Table 2). According to perturbation graphs (Figure 3), moisture content was affected significantly by the inlet air temperature.

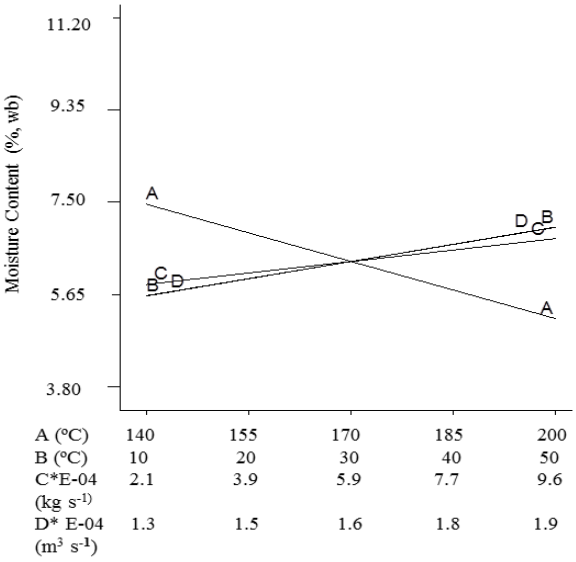

Figure 3. Perturbation plot of moisture content

A – Inlet air temperature, B – Feed temperature, C – Feed flow rate, D – Atomizing air flow

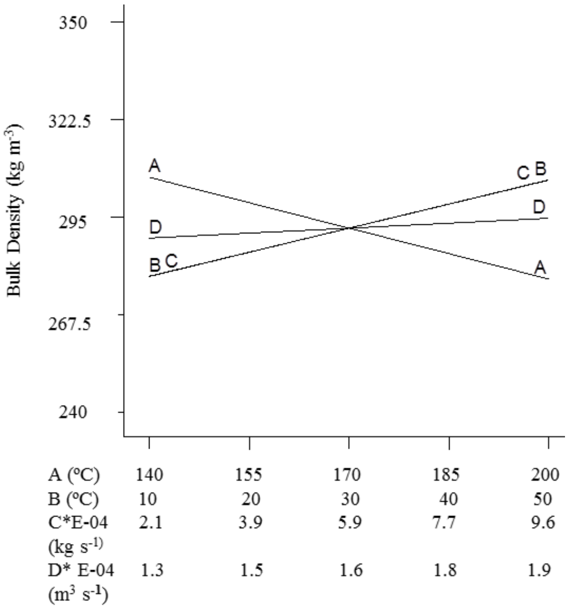

Figure 4. Perturbation plot of bulk density

A – Inlet air temperature, B – Feed temperature, C – Feed flow rate, D – Atomizing air flow

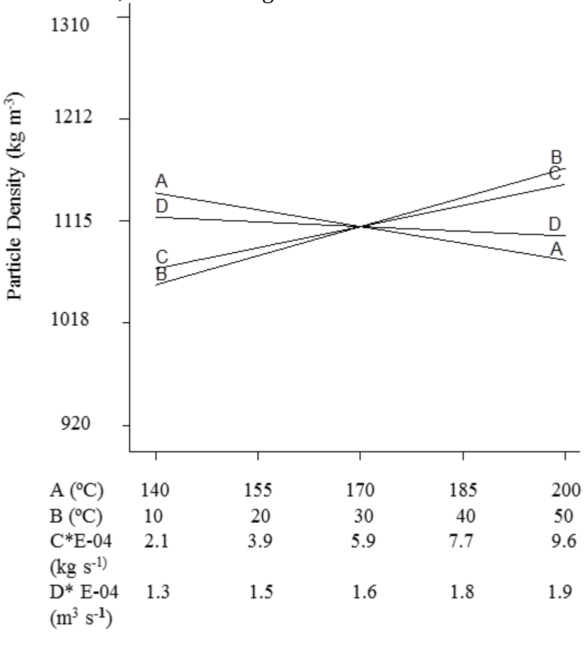

Figure 5. Perturbation plot of particle density

A – Inlet air temperature, B – Feed temperature, C – Feed flow rate, D – Atomizing air flow

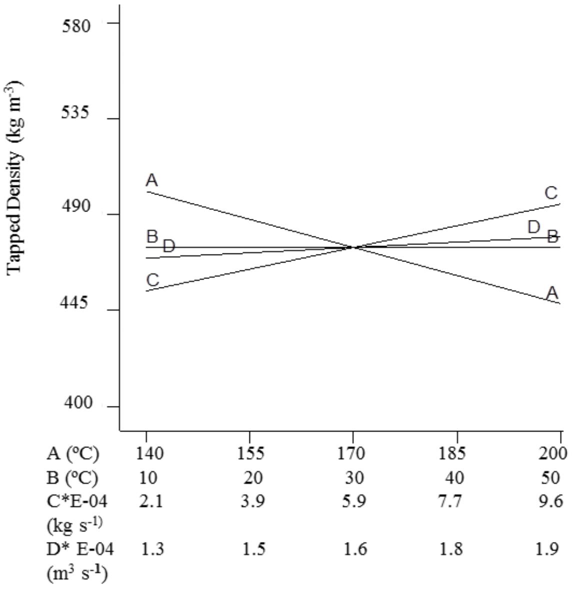

Figure 6. Perturbation plot of tapped density

A – Inlet air temperature, B – Feed temperature, C – Feed flow rate, D – Atomizing air flow

The bulk properties (bulk and tapped densities and porosity) of a food powder are highly dependent on particle size and its distribution (Barbosa-Cánovas et al., 2005). Lower bulk densities of a product are not desirable, resulting in a greater volume of package. Moreover, lower the bulk density, more occluded air within the powders would be and a greater possibility for product oxidation resulting in reduced storage stability (Kurozawa et al., 2009). The bulk densities of samples were changed in the range of 245 and

349 kg m^{-3} (Table 2). Bulk density and particle density were affected by all the independent variables except atomizing air flow (Figure 4 and 5) whereas tapped density was affected by only inlet air temperature and feed flow rate, respectively (Figure 6).

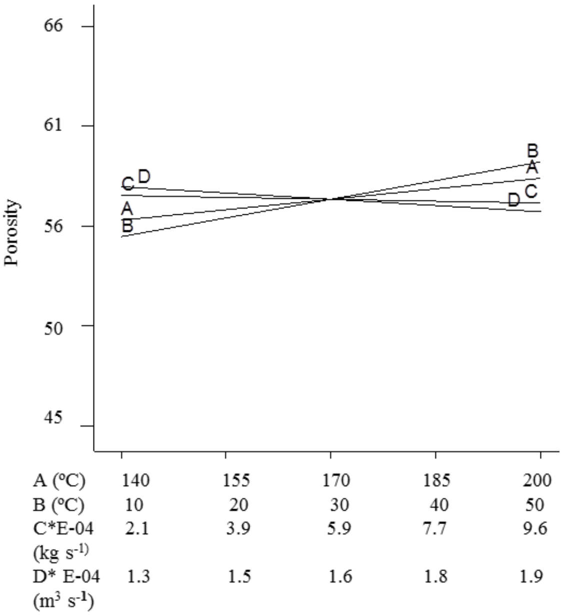

Figure 7. Perturbation plot of porosity

A – Inlet air temperature, B – Feed temperature, C – Feed flow rate, D – Atomizing air flow

Maximum porosity value (65.05) was recorded at inlet air temperature of 140 °C, feed temperature of 50 °C, feed flow rate 9.6E-04 kg s^{-1}and atomizing air flow 1.3 E-0.4 m^3 s^{-1} (Table 2). Spherical particles were packed in the best and thus, have the highest bulk densities and porosity (Reineccius 2004). Porosity was influenced by the feed temperature and atomization air flow (Figure 7).

Conclusions

In this study, physical properties of maltodextrin powders were investigated. The results showed that spray drying does not produce larger particles. The bulk, tapped and particle densities of spray dried maltodextrin were (<350), (<575) and (<1310) kg m^{-3}, respectively. These values are an indication that maltodextrin has fair porosity (65). For purposes of understanding the particle formation process, predicting product quality and evaluating the behavior of spray-dried maltodextrin during microencapsulation, this information will provide a helpful approach. Perturbation graphs revealed that atomizing air flow and inlet air temperature had more effect than feed temperature and feed flow rate on the physical properties of spray dried maltodextrin.

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