Influence of Maltodextrin and Spray Drying Process Conditions on Sugarcane Juice Powder Quality

Influencia de la Maltodextrina y Condiciones del Proceso de Secado por Aspersión en la Calidad del Polvo de Jugo de Caña Panelera

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Abstract. *Food powder liquid extracts obtained from fruits and vegetables can be manufactured using spray drying technologies while maintaining the quality attributes that are required by the industrial sector. The aim of this study was to evaluate the effect of maltodextrin and spray drying process conditions on sugarcane juice powder. A central composite design was used with a response surface analysis of four factors: (A) maltodextrin (10-20%), (B) inlet air temperature (130-150 °C), (C) outlet air temperature (75-85 °C) and (D) atomization speed (22,000–26,000 rpm). Moisture, hygroscopicity, solubility, effective recovery and formation of deposits on the walls presented significant differences (P<0.05) with respect to all factors, while, for water activity, no statistical differences were observed. The optimization of the factors found for the drying operating conditions were: (A) 20%, (B) 130 °C, (C) 75 °C and (D) 22,000 rpm, respectively.*

Key words: Sugar, juice, optimization, quality.

Resumen. *Polvos alimentarios de extractos líquidos obtenidos a partir de frutas y vegetales pueden ser manufacturados usando tecnologías de secado por aspersión y mantener los atributos de calidad requeridos en el sector industrial. El objetivo de este estudio fue evaluar el efecto de la adición de maltodextrina y las condiciones de procesamiento por secado por aspersión en la obtención de polvo de jugo de caña. Un diseño central compuesto y análisis mediante superficies de respuesta con cuatro factores estadísticos fue establecido: (A) maltodextrina (10-20%), (B) temperatura del aire de secado a la entrada (130-150 °C), (C) temperatura del aire a la salida (75-85 °C) y (D) velocidad del disco atomizador (22.000–26.000 rpm). Los resultados mostraron que las variables contenido de humedad del producto, solubilidad, recuperación efectiva y formación de depósitos de sólidos en la pared del secador son estadísticamente significativos (P<0,05) con respecto a los factores estudiados, mientras que la actividad de agua del producto seco final no muestra dependencia estadística significativa. Las condiciones de operación del secador por aspersión optimizadas en función de las propiedades fisicoquímicas del polvo y parámetros de operación del secador fueron (A) 20%, (B) 130 °C, (C) 75 °C and (D) 22.000 rpm.*

Palabras clave: Azúcar, jugo, calidad, optimización.

Saccharum officinarum L., commonly known as sugarcane, is a monocot plant from the Gramineae family. It is a giant grass related to sorghum and corn whose stem corresponds to the anatomical and structural section of the plant that has a greater economic value. This part is also of interest for the production of sugar, jaggery and biofuel, due to its chemical composition (Osorio, 2007), wherein saccharose is the most important carbohydrate. Jaggery is one of the products obtained from sugarcane juice with several economical, social, environmental, cultural, nutrition and food security impacts in Colombia (Rodríguez, 2002). Given the importance of the sugarcane industry to the Colombian economy, an alternative technology for the use of sugarcane juice is to obtain innocuous products with added value using spray drying.

Spray drying is by definition the transformation of a liquid system (solutions, dispersions, emulsions) into a dry particulate powder. The liquid system is atomized into droplets, which are dried through contact with a drying medium, usually air, at a high temperature. During the spray drying process, the droplets are reduced and the solvent (often water) is evaporated. Spray drying is commonly used in the food industry to ensure the microbiological stability of the products, reducing biological degradation and storage and transportation costs, obtaining a product with appropriate properties in terms of water activity, moisture content, pH, solubility, hygroscopicity, nutritional composition, glass transition temperature, color and fluidity, etc. (Fazaeli *et al*., 2012a; Chen and Patel 2008).

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The processing conditions of the spray drying process can produce sticky products, especially when the composition of the feed is rich in sugars and acids. This could generate an adherence of particles to the internal wall of the drying chamber, creating agglomeration and a lower product yield (Hennigs *et al*., 2001; Bhandari and Howes, 2005). The use of maltodextrins, gums, pectins, vegetable fibers, and starches as an encapsulation agent in spray drying has been widely studied (Adhikari *et al*., 2003; Ersus and Yurdagel, 2007; Tonon *et al*., 2008; Osorio *et al*., 2011; Wang and Zhou, 2012). These additives improve the properties of the finished product because there are increases of the glass transition temperature (Tg) and more stability during storage (Bhandari *et al*., 1997; Fazaeli *et al*., 2012a).

Fruit and vegetable food powders with the quality attributes required by the commercial sector can be obtained using a spray drying technology. This can be achieved through experimental optimizations, evaluating the effects of independent variables (formulation and processing) on response variables. Statistical techniques have been used for designing experiments, providing an effective way to optimize process conditions in order to attain the desired quality in the finished product (Woo *et al*., 2010; Fazaeli *et al*., 2012b). The response surface methodology (RSM) is a successful tool using mathematical and statistical techniques for developing, improving, and optimizing processes that describes the relationship between a response and the independent variables (Myers and Montgomery, 2009). In recent years, the RSM has been used to optimize the processing conditions of spray drying for starch derivatives (Drusch and Schwarz, 2006), insulin (Ståhl *et al*., 2002), diclofenac sodium (Rattes and Pereira, 2007), acai extract (Tonon *et al*., 2008), acerola extract (Moreira *et al*., 2009), pomegranate juice (Youssefi *et al*., 2009) and mandarin oil (Bringas *et al*., 2011).

The aim of this study was to assess the effect of maltodextrin and the operating conditions of a spray drying process to obtain powder from sugarcane juice.

MATERIALS AND METHODS

Raw material and spray drying processing. Concentrated sugarcane juice was obtained by an evaporation process carried out at a traditional sugarcane mill in a rural area (Girardota's town in the Department of Antioquia, Colombia) and stored under refrigeration at 4 °C. The spray dryer was supplied with concentrated sugarcane juice at 40 °Brix. The concentrated sugarcane juice was mixed with maltodextrin (DE of 19-20) and homogenized at 15,000 rpm for 5 min and filtered using a 500 µm mesh.

The drying process was carried out using a spray dryer with an atomizer disk (Vibrasec S.A.) with a water evaporation capacity of 1.5 L h^{-1} with the possibility to control the inlet and outlet air temperature and the atomizer disk speed, while the mass feed was kept constant. The drying equipment was operated under vacuum pressures and the powder was collected from the cyclone.

Physical and physicochemical characterization. The water activity (a_w) was determined with a dew point hygrometer at 25 ºC (Aqualab® series 3TE, Decagon Devices Inc.) (Cortés *et al*., 2007). The moisture content (Xw) was determined using the 925.45 official method of the AOAC (2002). The pH was determined with a pH meter (Hanna® pH 211) by submerging the electrodes in the sample after calibration using the 981.12 AOAC method. The soluble solids (°Brix) was determined through refractometer readings using the 932.12 AOAC method.

The acidity (%) was determined through titration with NaOH 0.1N using phenolphthalein as the indicator. It was expressed as a percentage of citric acid per 100 g of the sample using the 942.15 AOAC method.

The solubility (%) was determined using the Eastman and Moore method (Cano *et al*., 2005) with some modifications. The powder sample (1 g) was homogenized in 50 mL of H_2O and distilled in a vortex for 30 s. The solution was placed in a tube and centrifuged at 3,000 rpm for 5 min at 25 °C. A 25 mL aliquot of the supernatant was transferred to pre-weighed Petri dishes. Then, it was immediately placed in an oven for drying at 105 °C for 5 h. The solubility was calculated as the initial weight minus the final weight divided by the initial weight.

The hygroscopicity was determined using the gravimetric method. The samples (2–5 g) were placed inside a hermetic bottle with a constant relative humidity that was controlled with a supersaturated solution of KI (68.9% at 25 °C) (Martínez *et al*., 1998). To verify the condition for equilibrium between the samples and the environment, the weight of the samples was determined until reaching constant weight (± 0.001 g/g sample). The hygroscopicity was expressed in terms of moisture % (w.b).

The particle size distribution was measured using a Mastersizer® 2,000 laser light diffraction kit (Malvern Instruments Co.). The particle size was expressed as d(0.1), d(0.5) and d(0.9) (Finney *et al*., 2002; Jayasundera *et al*., 2011a).

Effective recovery and formation of deposits in the drying chamber. The effective recovery variable was determined in terms of percentage as the ratio of kg of solids in the powder obtained in the cyclone to the percentage of kg of solids in the feed. The formation of deposits was also measured in terms of percentage as the ratio of kg of powder attached to the inner wall of the dryer to the expected kg of product in the cyclone (Tonon *et al*., 2008)

Experiment design. The experimental design consisted of a composite central design and the optimization process was performed using a response surface with four independent factors. The experimental design explored points located within the levels and also outside them. The factors were: (A) maltodextrin content (10 - 20%), which is the amount of maltodextrin in the formulation, (B) inlet air temperature (130 - 150 °C), (C) outlet air temperature (75 - 85 °C), which was controlled through the feed mass, and (D) atomizer disk speed (22,000 to 26,000 rpm). There were 8 axial points, 8 factor points and 6 central points, thus generating 22 experiments that were analyzed statistically using the Design Expert 8.0 software and an analysis of variance (ANOVA) with a significance level of 5%. The response variables to be optimized were: % effective recovery (maximum), % of deposit formation in the drying chamber (minimum), water activity (minimum), moisture content (minimum), solubility of the powder (maximum) and hygroscopicity level (minimum). A regression analysis was solved with a second-order polynomial model according to Equation 1:

$$\begin{aligned} Y = {} & \beta_0 + \beta_A A + \beta_B B + \beta_C C + \beta_D D + \beta_{AB} AB + \beta_{AC} AC + \beta_{AD} AD \\ & + \beta_{BC} BC + \beta_{BD} BD + \beta_{CD} CD + \beta_{A^2} A^2 + \beta_{B^2} B^2 + \beta_{C^2} C^2 + \beta_{D^2} D^2 \end{aligned} \quad (1)$$

Where β_0 is a intercept, β_A, β_B, β_C and β_D are the coefficients of each factor; β_{A^2}, β_{B^2}, β_{C^2} and β_{D^2} are the coefficients of the double interaction and β_{AB}, β_{AC}, β_{AD}, β_{BC}, β_{BD}, β_{CD} are coefficients defined by the interaction between the factors (Bezerra *et al*., 2008).

Optimization and verification of model. The optimization process was performed using the methodology of response surface with a central composite experimental design with four factors: (A) maltodextrin (10 - 20%), which is the amount of maltodextrin in the formulation, (B) inlet air temperature (130 - 150 °C), (C) outlet air temperature (75 - 85 °C), which was controlled through the feed mass, and (D) atomizer disk speed (22,000 to 26,000 rpm). There were 8 axial points, 8 factorial points and 6 central points, thus generating 22 experiments. The Design Expert 8.0 software was used for the statistical analysis and a significance level of 5% was established

The following response variables were optimized: % effective recovery (maximum), % of deposit formation in the drying chamber (minimum), water activity (minimum), moisture content (minimum), powder solubility (maximum) and hygroscopicity level (minimum). Experimental data for the spray drying of the sugar cane juice were obtained by conducting the experiments under the recommended optimum conditions. Verification of the response surface model was performed by comparing the experimental value obtained from an independent set of samples with the predicted value obtained from the optimized model.

RESULTS AND DISCUSSION

Table 1 shows the average values of the physicochemical and physical parameters of the concentrated sugarcane juice and maltodextrin. The results shows that the

Table 1. Physical and physicochemical characterization of the raw materials.

Parameter	Concentrated sugarcane	Maltodextrin
Xw (%)	41.0 ± 0.1	4.5 ± 0.2
A_w	0.962 ± 0.002	0.116 ± 0.002
°Brix (%)	48.6 ± 0.1	95.2 ± 0.1
pH	5.71 ± 0.01	5.51 ± 0.16
Acidity (%)	0.026 ± 0.01	-
Viscosity (cp)	6.290 ± 0.01	-
Solubility (%)	-	96.05 ± 0.02

concentrated sugarcane juice used in the experiments was within the range of operating conditions of the spray drying equipment (°Brix <50% and viscosity <600 cp). Furthermore, the drying process was more efficient because the sugarcane juice had a lower moisture content than the juice obtained from the initial extraction process (Guzmán and Castaño, 2002). The maltodextrin was a powder with low moisture that exhibited good solubility and added no flavor or odor to the final product (Kenyon, 1995; Wang and Wang, 2000).

For each experiment in the experimental design, three samples of the powder were taken when the system reached stable state conditions to observe the reproducibility. Table 2 shows the average values and the standard deviation of the response variables according to the experimental design. Figure 1 shows the response surface to moisture content (a), product recovery (b), deposit formation (c), solubility (d), and hygroscopicity (e) in relation to the studied factors. Table 3 shows the coefficients of the polynomial model for the response variables according to equation 1.

Table 2. Results of the spray drying experiments for obtaining powder from sugarcane juice.

Run	Factors				Response variables					
	A (%)	B (°C)	C (°C)	D (rpm)	a_w	Moisture Xw	Effective recovery	Formation of deposits	Solubility	Hygroscopicity
						(%)				
1	15	140	80	20000	0.182	1.40	40.5	54.8	98.07	15.48
2	10	150	85	22000	0.185	1.14	14.3	81.2	98.09	17.20
3	20	150	85	26000	0.20	0.93	20.5	75.0	98.05	16.50
4	15	140	80	24000	0.182	1.26	25.2	70.8	98.07	10.59
5	10	130	85	26000	0.203	1.14	31.8	63.9	98.09	6.73
6	15	140	80	24000	0.183	1.25	29.5	67.7	98.09	10.5
7	15	120	80	24000	0.184	0.98	37.3	58.8	97.96	11.5
8	15	140	80	24000	0.181	1.24	26.6	69.6	98.07	9.14
9	20	150	75	26000	0.217	1.15	30.8	65.8	97.97	12.5
10	20	130	85	22000	0.191	0.90	70.3	25.6	97.87	10.2
11	25	140	80	24000	0.182	1.21	70.1	26.5	97.95	14.9
12	15	140	80	24000	0.183	1.21	28.1	67.7	98.08	9.14
13	15	140	80	24000	0.188	1.28	32.0	63.4	98.07	10.60
14	15	140	70	24000	0.227	1.01	43.1	52.2	98.01	7.26
15	10	130	75	26000	0.213	1.18	40.1	57.4	98.02	6.16
16	5	140	80	24000	0.185	0.88	19.2	76.0	98.01	6.47
17	20	130	75	22000	0.187	1.05	91.3	6.10	97.97	10.96
18	10	150	75	22000	0.205	1.05	18.2	77.5	97.98	7.54
19	15	160	80	24000	0.189	1.36	10.2	86.5	98.04	8.98
20	15	140	80	24000	0.204	1.26	32.6	62.8	98.07	9.15
21	15	140	90	24000	0.201	0.86	15.6	80.1	98.06	12.42
22	15	140	80	28000	0.185	0.89	45.6	49.7	97.99	7.44

The minimum and maximum values obtained for the response variables were: moisture (0.86 - 1.40%), water activity (0.181 - 0.227), effective recovery (10.2 -91.3%), formation of deposits in the drying chambers (6.1 - 86.5%), solubility (97.87 – 98.09%), and hygroscopicity (6.16 – 17.2%).

The summarized ANOVA showed significant differences ($P<0.05$) in terms of Xw with respect to factors A, B, C, D, and the interactions (but excluding the BC interaction). Nevertheless, this influence had low variability coefficients, as well as low average values (maximum value of 1.40%); this is consistent

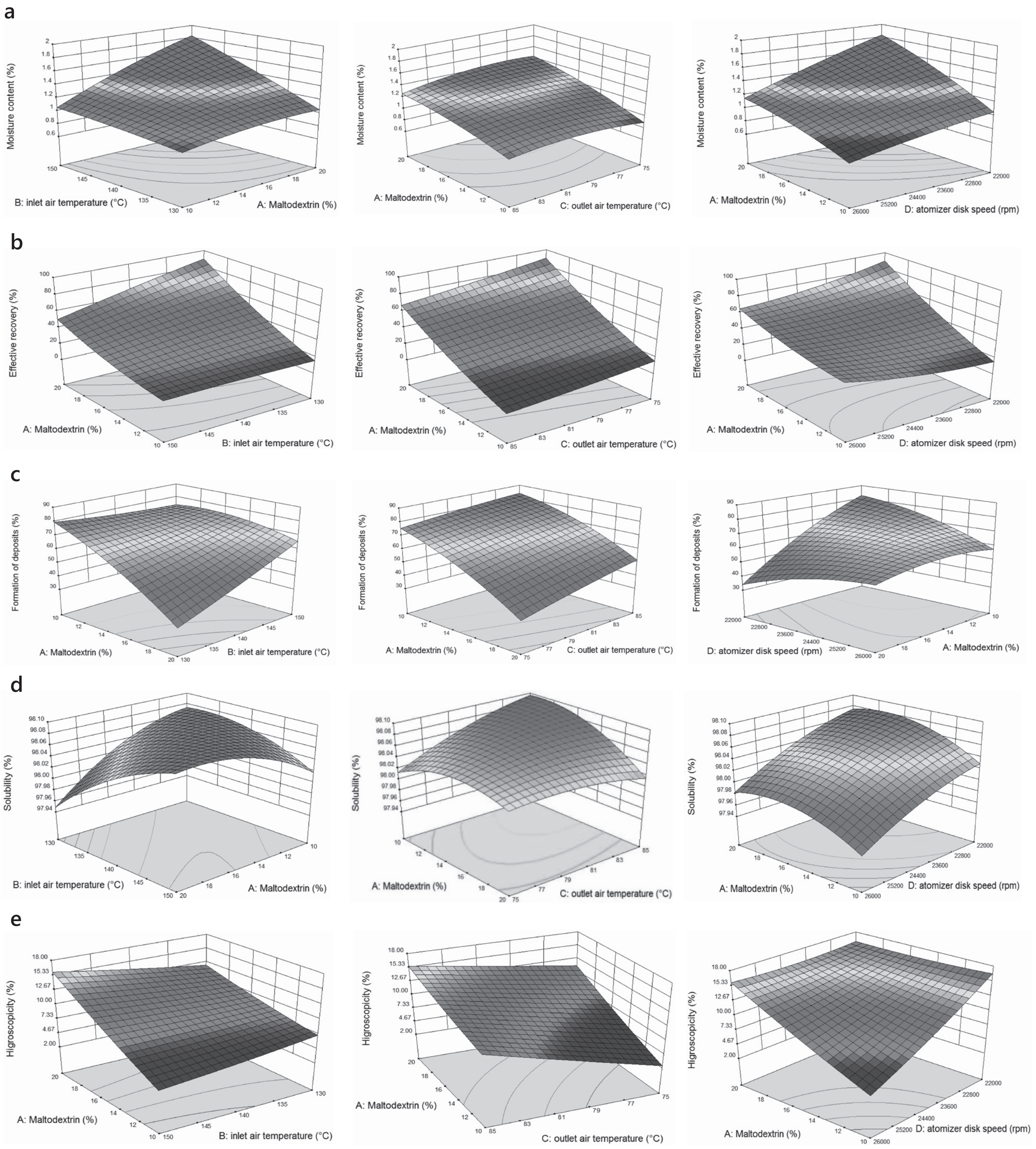

Figure 1. Response surface plots in relation to the processing conditions used to obtain powder from sugarcane juice: moisture (a), effective recovery (b), deposit formation (c), solubility (d) and hygroscopicity (e).

with the results found for a_w, which showed no significant differences ($P>0.05$) when compared with the factors and their interactions. This could be explained by the fact that, under all the evaluated processing conditions, the sugarcane powder had values that were close to the moisture of the monolayer. This suggests that the drying process was effective under the evaluated conditions.

Additionally, the values obtained in this study are similar to those reported in other studies on sorption isotherms of granulated jaggery (1.41% d.b) (Lara *et al*., 2008) and lower than those obtained in studies on sugarcane juice powder with maltodextrin (Largo, 2012), where the adsorption forces were maximal due to a stronger energetic interaction between the absorbent agent (water in the environment) and the absorbate (powder of sugarcane), which generates more sorption heat (Martinez *et al*., 1998).

Table 3. Main effects and interactions of the response surface models in the spray drying experiments for obtaining powder from sugarcane juice.

Regression coefficients	**Moisture Xw**	**Effective recovery**	**Formation of deposits**	**Solubility**	**Hygroscopicity**
			(%)		
Intercept	1.24	29.0	67.0	98.08	9.86
β_A	0.08	12.7	-12.4	-0.015	2.12
β_B	0.10	-6.8	6.9	0.020	-0.64
β_C	-0.04	-6.2	5.9	0.016	1.55
β_D	-0.13	NS	NS	-0.020	-2.01
β_{AB}	0.16	-10.1	10.2	0.047	1.63
β_{AC}	-0.05	NS	NS	-0.025	-1.00
β_{AD}	-0.10	-11.9	11.4	NS	2.97
β_{BC}	NS	NS	NS	0.027	1.60
β_{BD}	-0.14	NS	NS	-0.025	NS
β_{CD}	-0.03	NS	NS	0.017	NS
β_{A^2}	-0.05	4.5	-4.4	-0.025	NS
β_{B^2}	-0.02	NS	NS	-0.020	NS
β_{C^2}	-0.08	NS	NS	-0.011	NS
β_{D^2}	-0.03	4.1	-4.2	-0.012	0.47
R^2	0.9933	0.9842	0.9833	0.9898	0.9745
Regression (p-value)	<0.0001	<0.0001	<0.0001	<0.0001	0.0003
Lack of fit (p-value)	0.9385	0.0612	0.0931	0.1585	0.2522

Significant at $P<0.05$, NS: Non-significant coefficients.

On the other hand, these differences in Xw could be associated with the differences in the size of the atomized droplets, which modify the final moisture content values for the dry product and provide a distribution of particle sizes. In the case of the optimal point, which coincided with the conditions of experiment 17 (Table 2), the values were d_{10} = 9.5 µm, d_{50}= 20.9 µm and d_{90} = 41.6 µm (Figure 2).

According to the results presented in Figure 1, the moisture content had a very complex behavior that depended on the combinations of the studied factors. Nevertheless, the obtained moisture content values exhibited low variability among the different experiments. It was observed (Figure 1a) that this parameter decreased under the following conditions: a. increasing the maltodextrin content at a low air inlet temperature (130 °C) (higher total solids content and lower water content in the feed), b. decreasing the maltodextrin content at high air inlet temperatures (150 °C), c. increasing air inlet temperature at a low concentration of maltodextrin (10%) (higher evaporation capacity with low relative humidity which produces a higher driving force or chemical potential between air and drop (water), d. decreasing the inlet air temperature at high concentrations of maltodextrin (20%) (lower content of water in the feed), e. increasing the air outlet temperature (lower mass flow rate), f. increasing the rotation speed of the atomizer disk (smaller size of water droplet). Similar moisture content values have been reported in sugarcane powder (Guzmán and Castaño, 2002), but studies on sugar-rich fruits added with maltodextrin have reported higher moisture values (Chegini and Ghobadian, 2005; Kha *et al*., 2010; Gallo *et al*., 2011; Caparino *et al*., 2012). On the other hand, similar behaviors have been observed in the spray drying of orange juice when the inlet air temperature was increased (Goula and Adamopoulos, 2010). This has also been observed in formulations for sugar-rich foods when the moisture was reduced upon adding maltodextrin (Adhikari *et al*., 2009).

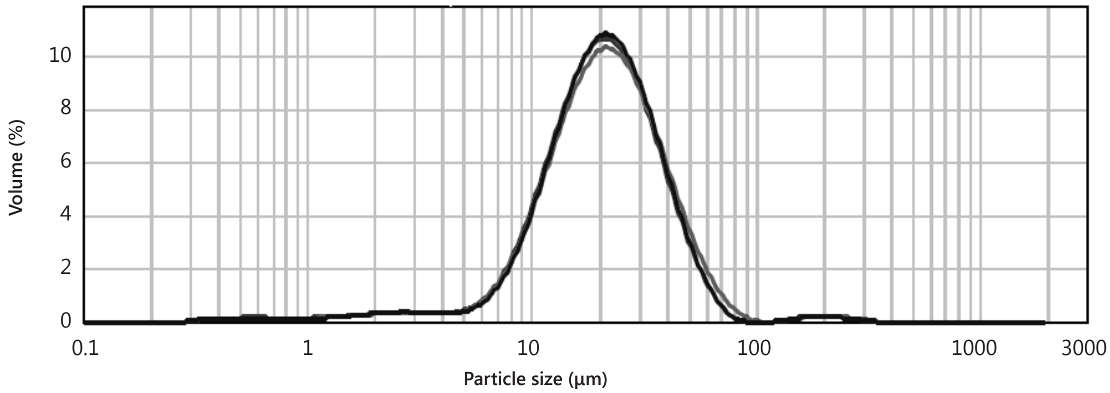

Figure 2. Particle size distribution of the sugarcane powder under the optimized conditions of the drying process.

The effective recovery of the product showed statistically significant differences ($P<0.05$) regarding factors A, B, and C, and interactions AB, AD, A^2, and D^2. The effective recovery was mainly reduced by increasing the inlet air temperature (factor B), this could be due to the fusion of existing carbohydrates (mainly saccharose, fructose, and glucose), which leads to an increase in the formation of deposits in the internal walls of the drying chamber. This phenomenon had statistically significant differences ($P<0.05$) for factors A, B, and C, and interactions A^2, D^2, AB, and AD. The values for effective recovery and formation of deposits for sugarcane were positively affected by the solids contribution of the maltrodextrin in the dryer's mass feed; this happens mainly at low inlet air temperatures (around 130 °C.) (Cai and Corke, 2000). Similar results have been reported for saccharose solutions which describe the behavior of sugar-rich foods (Bhandari *et al*., 1997; Jayasundera *et al*., 2011a).

Recent studies have shown that applying alternative drying aids such as proteins and surfactants with a low molecular weight may improve the recovery and quality of powder produced using spray drying (Goula and Adamopoulos, 2008; Jayasundera *et al*., 2011a; Jayasundera *et al*., 2011b; Jayasundera *et al*., 2011c). The University of Sydney has developed a type of protein that increases the recovery of sugar-rich materials by up to 80% by simply adding a small amount (<5%) in the fruit juice (Caparino *et al*., 2012).

The effective recovery of the product (Figure 1b) decreased as the maltodextrin content decreased. The reason for this is that a lower content of total solids in the mass feed produces less density; less density in turn means that a lower viscosity could lead to higher values of radial speed, thus causing the droplets to collide with the internal walls of the drying chamber at a greater speed and intensity. This could produce more deposits and reduce the yield of the process (Masters, 1991). Furthermore, increases in inlet and outlet air temperatures also decrease effective recovery (because it means greater evaporation capacity and adhesion of the product to the internal walls of the drying chamber due to fusion of the material). Likewise, reducing the speed of the disk while using smaller amounts of maltodextrin (10%) also decreases the effective recovery (a larger droplet with high levels of moisture generates more interparticle cohesion, meaning that greater amounts of the product are stuck to the internal walls of the drying chamber). Finally, increasing the speed of the atomizer disk while using larger amounts of maltodextrin (20%) also reduces the effective recovery (raising the speed of the atomizer disk produces smaller droplets which, at lower levels of moisture, require less evaporating heat and cause outlet air temperature to be higher, thus leading to increased adhesion to the internal walls of the drying chamber). The results obtained for this optimization process were higher than those reported in other studies during the spray drying process performed on saccharose solutions (maximum value of 56%) (Bhandari *et al*., 1997) and sugarcane juice carried out using atomization (maximum value of 60.18%) (Guzmán and Castaño, 2002).

It is important to take into account that adding maltodextrin to the dryer's mass feed (Figure 1b) caused an increase in the glass transition temperature (Tg) of the dry product. This is because the yield of the process was higher at high maltodextrin concentrations, low inlet air temperatures (130 °C), low outlet air temperature (75 °C), and low atomizer disk speeds. This could be explained by the fact that low drying temperatures generate less deposits inside the drying chamber. Similar results were reported for orange (Shrestha *et al*., 2007) and acai juice (Tonon *et al*., 2008). Additionally, in a study on spray drying with grape juice, the authors concluded that increasing the inlet air temperature decreased the process yield (Papadakis *et al*., 2006).

The values for formation of deposits (Figure 1c) on the internal wall of the drying chamber were consistent with those of product recovery, since they decreased as the maltodextrin content increased at low inlet and outlet air temperatures and atomizer disk speeds. Concentrated sugarcane juice is a very thermosensitive and sugar-rich food. Raising the inlet air temperature significantly reduces the process yield because the dry solid experiences a first-order transition upon fusion (Roos, 1995).

The solubility showed statistically significant differences ($P<0.05$) when compared to all the factors and interactions, except for the AD interaction. This proves that the formulation for the dryer's mass feed and the operating variables for the drying process play a key role. Generally speaking, the solubility of the sugarcane powder was high (>97%). The main reason is that sugars such as saccharose, glucose disaccharide, and fructose have high solubility; this is due to the high number of hydroxyl groups (OH) in the molecule (King *et al*., 1984; Dib-Taxi *et al*., 2003). Furthermore, maltodextrin, a derivative of the starch obtained from corn, is an encapsulation agent widely used in spray drying processes given its high values of solubility in water and its high glass transition temperature (Desai and Park, 2005; Ersus and Yurdagel, 2007). Instant solubility is directly related to the microstructure of the powder. A larger amorphous surface means that the powder will have more solubility in water; conversely, the presence of particles in a crystalline state results in lower solubility (Cano *et al*., 2005; Caparino *et al*., 2012).

Both moisture content and solubility were very dependent on the factors and their combinations. However, there were low variability coefficients. The solubility of the powder (Figure 1d) increased under the following conditions: when the maltodextrin content and the inlet and outlet air temperatures were high; when the maltodextrin content was low and the outlet air temperature was high (the high solubility of the maltodextrin and the thermal stress of the process might be generating a high and irregular specific surface, facilitating solvation during reconstitution), and when the atomizer disk speed was low and the maltodextrin concentration was medium (12 – 14%) (a larger particle size leads to a lower product temperature and a higher content of moisture, which could be causing agglomeration and increased apparent density in the product, which in turn cause more solubility and solvation). Similar results were reported for cape gooseberry (*Physalis peruviana* L.) powder with the addition of vitamins B_9, C, iron, and soluble fiber (Hernández, 2011), for apple juice (Araújo de Oliveira *et al*., 2009), and for saccharose powder with maltodextrin (Paramita *et al*., 2010).

The hygroscopicity showed significant statistical differences ($P<0.05$) in terms of factors A, B, C, and D as well as interactions AB, AC, AD, BC, and D^2. Particle size is an important parameter to determinate the surface area of the particles; smaller particles increase the surface area while the bigger particles decrease it. This leads to more water adsorption from the environment, depending on the active points in the dry matrix adsorption force (Nayak and Rastogi, 2010; Sudeep *et al*., 2010). This situation may lead to agglomeration of the product during storage. The results for hygroscopicity show that sugarcane powder is a hygroscopic product that can reach moisture levels ranging from 6 to 17% (w.b) in an environment whose relative humidity is 68.7%.

In general, the hygroscopicity (Figure 1e) of the sugarcane powder decreased when there was low content of maltodextrin, mainly when the system had a high inlet air temperature, low air outlet temperature, and high atomizer disk speed. These results are consistent with studies in which the physical changes occurring at low moisture levels with a high content of sugar in the dehydrated food included a high hygroscopicity. This could be due to the glass transition temperature Tg (Roos, 1993). Likewise, similar hygroscopicity values have been reported in studies on mango pulp drying using maltodextrin (Caparino *et al*., 2012) and tomato pulp (Goula and Adamopoulos, 2008).

Generally speaking, all the regression coefficients (R^2) of the quadratic mathematical models that fit to the response variables were greater than 97%. This is very representative for determining these and other independent variables (factors) within the assessed ranges.

Optimization process. In order to obtain sugarcane juice powder while minimizing the moisture content, formation of deposits in the dryer, and hygroscopicity level and maximizing the effective recovery and solubility, the optimal drying conditions were determined based on the combination of multiples responses. a_w was not considered because it did not present any statistically significant differences. Multiple graphical and numerical optimizations were carried out using the Design Expert 8.0 software to determine the optimum level of the independent variables with desirable response goals. One optimal condition was obtained for several responses given the following operating conditions: percentage of maltodextrin in the formulation (20%), atomizer disk speed (22,000 rpm), inlet air temperature (130 °C), and outlet air temperature (75 °C). Table 4 shows the values obtained at optimal experiment conditions and the values according to the polynomial model for each response variable.

Table 4. Response variables for the optimal conditions for obtaining powder from sugarcane juice.

Variable	**Values**	
	Experimental	**Theoretical (from model)**
Moisture content (%)	1.11 ± 0.02	1.05 ± 0.02
Water activity (a_w)	0.183 ± 0.001	0.183 ± 0.001
Effective recovery (%)	91.19 ± 0.46	89.73 ± 4.33
Formation of deposits (%)	7.31 ± 0.61	7.07 ± 4.40
Solubility (%)	98.06 ± 0.02	97.97 ± 0.01
Hygroscopicity (%)	10.96 ± 0.01	10.95 ± 0.88

Verification of the model. Three experiments were carried out under the recommended optimum conditions to test the adequacy of the response surface model in predicting the optimum response values. The observed experimental and predicted values are given in Table 4. The experimental response values were in agreement with the predicted values as no significant difference ($P>0.05$) was found between the experimental values and the predicted values.

CONCLUSIONS

The response variables moisture, effective percentage of recovery, formation of deposits, solubility, and hygroscopicity were affected by the feed composition and the processing conditions for obtaining powder from sugarcane juice. The optimal independent variables for this process were: maltodextrin (20%) in the composition of the feed, atomizer disk speed (22,000 rpm), inlet air temperature (130 °C) and outlet air temperature (75 °C).

Since sugarcane powder is a sugar-rich food product, it is recognized as heat-sensitive and requires encapsulating additives such as maltodextrin for the spray drying process to be successful. The evaluated physicochemical properties for the sugarcane powder presented adequate quality characteristics that make it suitable for direct consumption or for reconstitution in water. Furthermore, it could also be used as an ingredient in food industries.

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