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Spray drying of soymilk: evaluation of process yield and product quality

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Abstract
The aim of this work was to evaluate the effect of inlet air temperature and gum Arabic concentration on yield of spray drying of soymilk and powder quality (moisture content, water activity and antioxidant capacity). Since soymilk had a significant lipid content, gum Arabic played a significant role as an emulsion stabilizer, improving process yield and preserving antioxidant capacity. However, temperature did not affect antioxidant capacity. The optimal condition to obtain higher antioxidant capacity was: 30% of gum Arabic and 160°C. The powder obtained under optimized condition was characterized regarding to bulk density, particle size distribution and morphology.

Keywords: *soymilk; spray drying; ferric reduction power FRAP; DPPH scavenging ability; scanning electron microscopy.*

1. Introduction

Recently, the ready-to-drink soymilk has become popular, in which sales volume of worldwide in 2015 reached 13.5 billion liters[1]. Vegan and helthy diet folowers are one of the major consumers because it is lactose- and gluten-free beverage and contains high-quality proteins, dietary fiber and antioxidant compounds, such as phenolic compounds[2,3]. However, some conservation method is necessary in order to increase its shelf life. Of the several drying methods, spray drying is suitable for heat-sensitive products, such as soymilk, promoting higher retention of nutrients due to the short residence time[4].

When exposed at higher temperature during spray drying, fat present in soymilk (18 g/100 g solids)[5] becomes molten, resulting in particle adhesion on the dryer chamber and low product recovery[6]. Part of this problem can be solved by adding a carrier agent to the feed solution before drying, in order to decrease the fat content[7]. Moreover, since soymilk is an oil-in-water emulsion, the thermodynamic instability of this system can result in larger oil droplets due to coalescence of droplets dispersed in soymilk. The larger the oil droplets are, the higher the breakup during atomization of the emulsion in the spray dryer chamber[8]. This breakup of the emulsion favors the increase in of the surface oil, decreasing the product recovery[9]. Thus, the addition of carrier agent with good emulsifying properties, such as gum Arabic, enhances emulsion stability and, as consequence, product recovery.

The objective of this work was to evaluate the effect of inlet air temperature and gum Arabic concentration on the process yield and powder quality (moisture content, water activity and antioxidant capacity).

2. Materials and Methods

2.1. Material

Soybean (*Glycine max* (L.) Merr.) cultivar BRS 257, which is lipoxygenase-free, was acquired from SL Alimentos (Mauá da Serra, Brazil). Gum Arabic (GA) Instantgum BB (Nexira, São Paulo, Brazil) was used as the wall material. DPPH 2,2-diphenyl-1-picrylhydrazyl and TPTZ 2,4,6-tris(2-pyridyl)-S-triazine were used as reagent for the analysis of antioxidant capacity, and Trolox 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid as standard (Sigma-Aldrich, Saint Louis, USA).

2.2. Preparation of soymilk

Soymilk was obtained according to Baú and Ida[2]. About 3 kg of soybeans were soaked in water at 1:3 ratio (w:w, soybean:water) for 12 h at 8°C. The grains were drained and homogenized with distilled water at 1:8 ratio (w:w, soybean:water) using an industrial blender. The slurry was filtered and pasteurized at 90°C for 3 min, obtaining the soymilk. The chemical composition of soymilk, obtained by AOAC[10], was (wet basis): moisture content of 94.8±0.1%, ash content of 0.2±0.0%, lipid content of 1.3±0.1%, protein content of 2.4±0.0% and carbohydrate content, calculated by difference, of 1.4%. Samples were stored at -18°C and thawed according to the quantity required for spray drying.

2.3. Spray drying of soymilk

Before spray drying, gum Arabic was dissolved in soymilk at different concentrations (Table 1) using a magnetic stirrer. After, the mixture were homogenized at 20,000 rpm for 5 min in order to emulsify the fat soymilk and break up the clots, returning to a fluid consistency. About 400 g of feed solution were fed into the laboratory scale spray dryer (MSD 1.0, Labmaq, Ribeirão Preto, Brazil) by a peristaltic bomb at flow rate of 0.4 L/h. The feed solution was atomized into spray dryer chamber by a two-fluid atomizer spray nozzle with an orifice of 0.7 mm in diameter, using compressed air at flow rate of 40 L/h. Inlet air temperature was used according to Table 1. For each assay, the collected powder was weighed for subsequent calculation of process yield, which was the ratio of total solids mass in the powder to total solids mass in the feed solution.

Spray drying experiments were carried out according to a central composite rotatable design (Table 1) in order to evaluate the effect of inlet air temperature and gum Arabic concentration on the responses process yield, moisture content, water activity and antioxidant capacity. Experimental data were fitted to Equation (1) [11].

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_{11} x_1^2 + b_{22} x_2^2 + b_{12} x_1 x_2 \quad (1)$$

Where: y is the response, b_0, b_1 and b_2, b_{11} and b_{22}, and b_{12} are the constant, linear, quadratic and cross-product regression coefficients, respectively, and x_1 and x_2 represent the coded values of the T_{in} and GA variables, respectively.

Regression coefficients of the predictive models were obtained by the Protimiza software (http://experimental-design.protimiza.com.br). Coefficients within a confidence level above 90% were considered significant (p<0.1). Non-significant terms were eliminated, and the model was tested for adequacy by analysis of variance (Anova), coefficient of determination (R^2) and F-test. For powder moisture content, the analysis of results indicated the model was linear, and the expansion of the screening design to a central composite rotatable design, with the addition of axial points (tests 5 to 8), was not necessary.

Table 1. Screening design for spray drying of soymilk, regression coefficients and Anova

Assay	Independent variables		Dependent variables				
	T_{in}	GA	Y	X	Aw	FRAP	DPPH
1	140	13	45.6	2.6±0.1	0.149±0.006	25.1±2.0	243.3±14.8
2	180	13	54.1	1.1±0.0	0.093±0.010	30.2±0.3	223.6±13.5
3	140	27	59.2	3.5±0.4	0.043±0.002	44.9±3.9	514.3±15.7
4	180	27	60.5	1.4±0.4	0.088±0.005	46.6±0.8	482.4±5.2
5	132	20	64.9	-	0.112±0.009	40.3±2.3	330.3±39.5
6	188	20	57.0	-	0.170±0.004	36.6±0.5	285.3±24.5
7	160	10	40.1	-	0.165±0.012	26.6±0.7	168.3±10.4
8	160	30	60.7	-	0.095±0.008	43.7±1.1	543.3±26.5
9	160	20	69.8	2.2±0.1	0.168±0.012	43.7±1.1	343.6±3.5
10	160	20	64.2	2.0±0.2	0.108±0.016	37.0±0.6	293.2±31.3
11	160	20	66.6	2.4±0.0	0.122±0.006	37.4±0.8	319.3±8.7
Regression coefficients							
	b_0		66.9	2.2	0.12	36.9	327.6
	b_1		NS	-0.9	NS	NS	-14.4
	b_{11}		-3.2	-	NS	NS	NS
	b_2		6.1	0.3	-0.03	7.6	132.52
	b_{22}		-8.4	-	NS	NS	22.18
	b_{12}		NS	NS	NS	NS	NS
	R^2		0.88	0.95	0.36	0.90	0.98
	Fc		17.2	38.0	5.0	80.3	124.3
	Ft		3.07	4.32	3.36	3.36	3.07

NS is non-significant (p>0.1)

2.4. Analytical methods

2.4.1. Physicochemical properties of the powders

Moisture content was determined gravimetrically in triplicate in an oven at 105°C for 24h[10]. A thermohygrometer Aqualab (4 TEV, Decagon, Pullman, USA) was used to measure water activity at 25°C. Bulk density was calculated by dividing the mass of powder by the volume occupied in the cylinder after tapped by hand. Particle size distribution and mean diameter particle D_{43} were obtained, in triplicate, using a laser light scattering analyzer (Mastersizer, model 2000, Malvern, UK). Particle microstructures were evaluated by a scanning electron microscope (Leo 440i, LEO Electron Microscopy/Oxford, Cambridge, England).

2.4.2. Antioxidant capacity of the powders

Prior to the analysis, 0.5 g of powder were dissolved in 8 mL of destilled water. Antioxidant capacity by donating hydrogen atoms to the DPPH radical and by ferric reduction power FRAP were determined according to Brand-Williams et al.[12] and Benzie and Strain[13], respectively. For DPPH and FRAP method, after reaction, the sample absorbance was measured at 517 and 595 nm, respectively, using an UV-visible spectrophotometer. Analytical curves with different concentrations of Trolox, ranging from 1,000 to 5,000 µM for DPPH and 50 to 600 µM for FRAP method, were used for the subsequent calculation of the results in µmol Trolox equivalent (TE)/g of soymilk solids. All assays were performed in triplicate.

3. Results and discussion

3.1. Spray drying of soymilk

The regression coefficients for the responses, F-values, p-values and R^2 are presented in Table 1. After exclusion of non-significant terms ($p>0.1$), the predictive models were tested for accuracy of fit by Anova. When the calculated F-value Fc was greater than the tabulated F-value Ft, the variation was explained by the regression and not by the residues. Thus the regression was significant, and the model could be considered predictive. Figure 1 shows the response surfaces generated by the proposed models.

Analyzing Figure 1(a), GA had greater influence on process yield than T_{in}. As expected, the increase of GA up to 22.5% enhanced powder recovery, since the addition of carrier agent decreased the fat content in the feed solution. This fact reduces the particle adhesion on the dryer chamber, which could occur due to the fat melting during spray drying[7]. However, an opposite behavior could be seen at GA above 22.5%. This result can be related to the high powder moisture content (Fig. 1(b)). Higher carrier agent concentration increases the feed viscosity, resulting in greater droplets atomized during spray drying. Thus, there is a poor heat and mass transfer between the droplets and drying air, resulting in the formation of wetter and sticker particles.

The antioxidant capacity of spray-dried soymilk ranged from 168.3 to 543.3 µmol TE/g for DPPH and 25.1 to 46.6 µmol TE/g solids of soymilk for FRAP method. Since soymilk solution presented 742.6±36.2 and 200.2±6.2 µmol TE/g solids, there was a retention of antioxidant capacity varying from 22.7 to 73.2% and 12.5 to 23.3%, for DPPH and FRAP methods, respectively. Figures 1(c) and 1(d) show the positive effect of gum Arabic concentration on antioxidant capacity for both methods. Since soymilk had a significant lipid content, gum Arabic played a significant role in spray drying as an emulsion stabilizer, encapsulating and preserving the antioxidant substances present in soymilk.

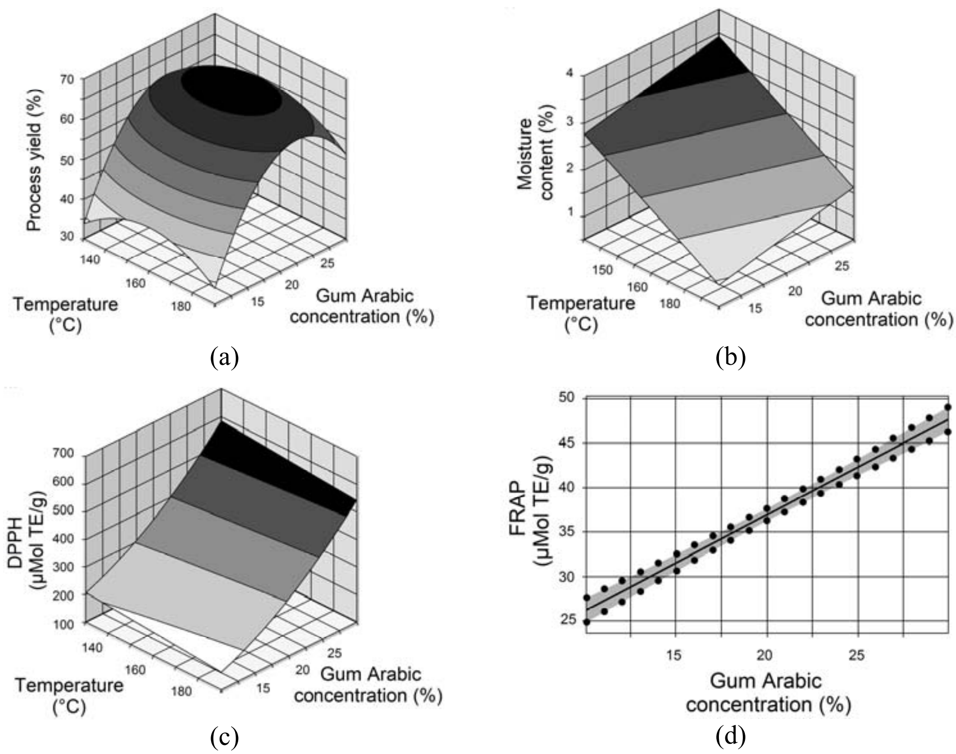
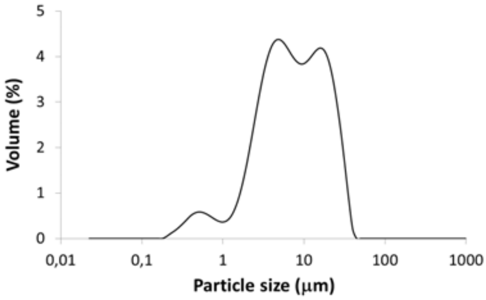


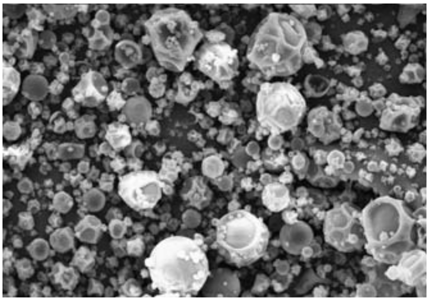
Fig. 1. Influence of independente variables on the responses: (a) process yield, (b) moisture content and (c) antioxidant capacity by DPPH and (d) FRAP methods

3.2. Characterization of the powder obtained under the optimum condition

HIgher process yield and antioxidant capacity were obtained at 160°C and 30% of GA. Under this optimum condition, process yield was 58.7%. The powder presented moisture content of 1.5±0.2%, antioxidant capacities by FRAP and DPPH methods of 38.9±1.6 µmol TE/g and 586.0±0.1 µmol TE/g, respectively; bulk density of 0.40±0.01 mg/ml and mean diameter size of 9.18±0.33 µm. Particle size distribution and the morphology evaluated by scanning electron microscopy were shown in Figure 2. Particles presented a continuous wall without fissures or cracks. Such characteristics is desirable to effectively protect the antioxidant compounds. However, particles had an irregular structure, which adversely affect the flow properties of the powders. This morphology can be result from slow film formation during drying of the atomized droplets, causing their shrinkage during the final stages of drying and cooling[14].



(a)



(b)

Fig. 2. Particle size distribution (a) and micrograph of the spray-dried soymilk with magnification of ×2000 (b)

4. Conclusions

This work demonstrated the significant role of gum Arabic in spray drying of soymilk as an emulsion stabilizer, since there was an improvement on product recovery and retention of antioxidant capacity. In order to obtain maximum process yield and antioxidant capacity, the optimal condition was proposed: 30% of GA and 160°C, in which process yield was 58.7%. There was a siginificant retention of antioxidant capacity by donating hydrogen atoms to the DPPH radical (78.9%) after spray drying; however only 19.4% of ferric reduction power of soymilk solution was preserved.

5. Nomenclature

Aw	water activity	
DPPH	DPPH scavenging ability	µmol TE/g soymilk solids
FRAP	ferric reduction power	µmol TE/g soymilk solids
GA	gum Arabic concentration	%
T_{in}	Inlet air temperature	°C
X	moisture content	% (wet basis)
Y	process yield	%

6. Acknowledgements

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