Study of the flash drying of the residue from soymilk processing - "okara"

Estudo da secagem em flash dryer do resíduo – "okara" – resultante do processamento do leite de soja

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Abstract

The objective of this research project was to study the drying of soymilk residue in a pneumatic flash dryer, using Response Surface Methodology(RSM), and to evaluate the quality of the dried residue. Soymilk residue, also known as okara, was provided by a Brazilian soymilk factory. RSM showed that for a 120 second drying cycle, the lower the residue moisture contents (y) obtained, the higher the recirculation rates (x_1), regardless of the air drying temperature (x_2), and it could be expressed by the equation $y = 7.072 - 7.92x_1$, with $R^2 = 92,92\%$. It is possible to obtain okara with 10% of moisture (dwb) under the condition $x_1=1.25$, equivalent to RR = 61%, with air drying temperatures ranging from 252 °C to 308 °C. The dried okara obtained through Central Compound Rotational Design (CCRD) presented a centesimal composition similar to the okara dried in a tray dryer, known as the original okara. There were significant variations ($p \leq 0.05$) in the Emulsifying Capacity (EC), Emulsion Stability (ES) and Protein Solubility (PS) between the dehydrated residues obtained. It was concluded that the flash drying of okara is technically feasible and that the physicochemical composition of the residue was not altered; on the contrary, the process promoted a positive effect on the technological functional properties.

Keywords: soymilk residue; drying; pneumatic dryer; technological functional properties.

Resumo

O objetivo deste projeto de pesquisa foi estudar a secagem do resíduo do leite de soja em secador pneumático *flash dryer* utilizando a Metodologia de Superfície de Respostas (MSR) e avaliar a qualidade do resíduo desidratado. O resíduo do leite de soja, também conhecido como okara, foi fornecido por indústria brasileira. A MSR demonstrou que, para um ciclo de 120 segundos de secagem, menores teores de umidade (y) são obtidos quando maior a taxa de recirculação (x_1), independente da temperatura do ar de secagem (x_2), e pode ser expressa pela equação: $y = 7,072 - 7,92x_1$ com $R^2 = 92,92\%$. É possível obter okara com 10% de umidade (b.u.) na condição $x_1=1,25$ equivalente a RT=61% e ar de secagem na temperatura de 252 °C a 308 °C. O okara obtido pelo Delineamento Central Composto Rotacional (DCCR) apresentou composição centesimal semelhante ao resíduo desidratado em secador de bandejas, denominado resíduo original. Houve variação significativa ($p \leq 0,05$) na Capacidade de Emulsificação (CE), Estabilidade da Emulsão (EE) e Solubilidade da Proteína (SP) entre os okaras desidratados. Podemos concluir que a secagem do okara em *flash dryer* é viável tecnicamente e não alterou a composição físico-química do okara, ao contrário, promoveu efeito positivo nas propriedades funcionais tecnológicas.

Palavras-chave: resíduo de leite de soja; secagem; secador pneumático; propriedades funcionais tecnológicas.

1 Introduction

There is an urgent need to develop technology in order to use the residue resulting from soymilk processing, also known as okara, due to the large volume produced, which, according to Costa and Mori (1978) and Grizotto et al. (2006), is about 2 to 3 tons per ton of soybean processed. The okara produced contains 85 g.100g^{-1} moisture and a high protein content (40 g.100 g^{-1} on a dry weight basis) (GRIZOTTO et al., 2006) and deteriorates rapidly if no conservation method is applied (AGUIRRE et al., 1981).

The drying technique is the most viable means of conserving this residue, allowing for considerable economy in handling, storage and transportation costs (AGUIRRE et al., 1978). Travaglini et al. (1980b) studied the drying of okara in a tray dryer with forced air circulation at 65 °C, and observed that the quality of the protein was maintained, with about 96% destruction of the trypsin inhibitor factor. According to these authors, the inconvenience of this method was the low

productivity, since it is a discontinuous process requiring long drying periods. Aguirre et al. (1981) reported that the drying of okara in a drum dryer resulted in a better product than that dried in a tray dryer, as far as the protein quality was concerned, showing a Protein Dispersibility Index (PDI) between 8 and 20%, indicating that the drying procedure did not depreciate the quality of protein. Nevertheless, the disadvantage of this method was the elevated cost of the equipment.

When drying okara, one of the most important aspects to be considered is the preservation of the protein quality, which can be affected by the drying conditions. The okara protein is of extremely high quality and the amino acid profile, determined by the Protein Efficiency Ratio (PER), is slightly superior to that of the soymilk itself, according to reports by Hackler et al. (1963) and Travaglini et al. (1980a,b). In addition, Bowles and Demiate (2006) and Jackson et al. (2001) showed that approximately 1/3 of the isoflavones present in the soybean remains in the okara,

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suggesting that it is a good, low cost source of nutrients for human nutrition.

In addition to the nutritional aspect, the knowledge of the technological functional properties of the dehydrated okara is essential, in order to evaluate its applications as a food ingredient. The term "technological functional property", when applied to a food ingredient, can be defined as all non-nutritional properties that influence the production and quality of a determined food. Most of the functional properties influence the sensory character of the food, mainly the texture, but they can also have important roles in the physical behavior of foods (CHEFTEL; CUQ; LORIENT, 1989).

The pneumatic flash dryer basically consists of a long tube with a variable length of up to 20 m, depending on the evaporative capacity (PERRY et al., 1963). The material to be dried is transported through the tube by a current of hot air at high speed, impelled by potent fans. The pneumatic dryer is indicated for granular materials that fluctuate when dispersed in air current, such that they do not agglomerate or stick to the transporter walls. Coarse materials with high moisture contents should be ground in a hammer mill before drying, and it is possible to re-circulate dried material by mixing it with still moist material, dispersing the resulting mixture in a disintegrator before entering the dryer. However, literature on drying, using pneumatic flash dryer, is scarce and there are few pilot scale devices available for tests - the only paper available is a study of the flash drying of cassava flour by Brunelo and Hufenuessler (1990), carried out at the Polytechnic College of USP, São Paulo, Brazil.

The general objective of the present study was to establish the following conditions for drying okara in a pneumatic flash dryer: drying air temperature (T °C) and the recirculation rate of the dry residue (RR %), using response surface methodology based on the physicochemical composition and the technological functional properties of the dehydrated okara.

2 Materials and methods

2.1 Raw material

Three hundred eighty kilograms of the residue from soymilk production known as okara, with 82.87 g.100 g^{-1} moisture content, were provided by a Brazilian factory located in São Paulo, Brazil. This industrial unit was chosen from a total of nine factories based on the criterion of its location, in the Southeast of Brazil. Considering that this factory used the most adequate cultivar for the region where it was located, the cultivar had the greatest agricultural diffusion adapted to the Southeast and part of the Center-West regions of the country. The okara was transported to the Institute of Food Technology, ITAL, in Campinas, Brazil in double plastic bags, and it was stored in cold chambers with air circulation at 10 °C until processing.

2.2 Physical-chemical determinations

The following determinations were carried out in both the original okara and the one dehydrated in the flash dryer: crude protein content (ASSOCIATION...,

2005), lipid content by the Bligh-Dyer method (CECHI, 1999), moisture content (ASSOCIATION..., 2005), fiber in neutral detergent (FDN) (AMERICAN..., 2003), ash content (ASSOCIATION..., 2005) and carbohydrates - calculated by difference [100 – (moisture+protein+lipid+ash+fdn)].

The determinations were performed in triplicate and the results expressed in dry weight basis (dwb) or wet weight basis (wwb).

2.3 Technological functional properties

The technological functional properties evaluated in the original okara and in the one dehydrated in the flash dryer were: Protein Solubility (PS), Water Holding Capacity (WHC), Emulsifying Capacity (EC) and Emulsion Stability (ES), as described below.

Protein Solubility (PS) was evaluated at pH 3, 5 and 7 in a saline solution (0.1M NaCl), with the pH adjusted using 0.1N NaOH or 0.1N HCl (MORR et al., 1985). The suspensions were stirred for one hour at room temperature, and after centrifugation, the soluble protein contents of the supernatants were determined by the micro Kjeldahl method (ASSOCIATION..., 2005). The percentage of soluble protein was calculated using Equation 1:

$$PS = \frac{protein\ concentration\ in\ supernatant\ (mg.mL^{-1}) \times 50 \times 100}{weight\ sample\ (mg) \times \dfrac{protein\ content\ of\ sample\ (\%)}{100}} \tag{1}$$

Water Holding Capacity (WHC) was determined according to Regenstein, Gorimar and Sherlon (1979). The pH values of the suspensions were adjusted to pH 3, 5 or 7 with 0.1N to 1.0N NaOH or HCl, and the final volumes adjusted to result in 1% protein dispersions. After stirring for 1 hour at room temperature, 20 mL aliquots were centrifuged at 30,000 G for 15 minutes at 5 °C. The supernatant of each sample was reserved and the moisture (ASSOCIATION..., 2005) and protein (ASSOCIATION..., 2005) contents of the precipitates were determined. The water holding capacity was calculated using Equation 2 and it was expressed in grams of water per gram of protein (g H$_2$O.g^{-1} protein):

$$WHC = \frac{hydrated\ weight - original\ weight}{sample\ weight} \tag{2}$$

Emulsifying Capacity (EC) was determined according to De Kanterewicz et al. (1987) with some adaptations. It was defined as the maximum amount of oil that could be dispersed in 100 mL of the protein dispersion prepared with "okara" flour with a particle size below 180 µm (80 mesh sieve), prepared in distilled water and containing approximately 1% of protein. Vegetable oil was added to the dispersion at a rate of 1 mL oil per minute, until the point when the emulsion collapsed, visualized by change in color and phase separation. The emulsion was prepared in a Turratec homogenizer (Ultra Turrax T-25, TECNAL, Brazil) at 18,800 rpm, maintaining the temperature at about 4 to 5 °C in ice bath. The dispersion/oil proportion immediately prior to the point of collapse was considered in the calculation of the EC. The emulsifying capacity was defined as the volume (mL)

of oil added before reaching the inversion point, per gram of protein, according to Equation 3:

$$EC = \frac{volume\ of\ oil\ (mL.100\ mL^{-1}\ dispersion)}{protein\ concentration\ of\ sample\ (g.100\ mL^{-1}\ dispersion)} \quad (3)$$

Emulsion Stability (ES) was determined according to Acton and Safle (1970), with some adaptations according to the conditions of the laboratory used. The stable emulsion obtained with the protein dispersion plus oil, according to the procedure described above for EC, was maintained for 24 hours at room temperature (22 ± 2 °C). Five milliliter aliquots were removed for the moisture determinations from both the freshly prepared emulsion and the emulsion after 24 hours. ES was calculated using Equation 4:

$$ES = \frac{100 - M^{24h}}{100 - M^{original}} \times 100 \quad (4)$$

where:

ES = emulsion stability

$M^{24\,h}$ = moisture after 24 hours

$M^{original}$ = moisture of the freshly prepared emulsion

The determinations were carried out in triplicate and the results expressed in a wet weight basis (wwb).

2.4 Drying of the okara in the flash dryer

The pneumatic flash dryer used in these trials was manufactured by Volpi Metallurgical Company, Jaraguá do Sul, Brazil, and it is currently at the Food Technology Institute (ITAL) in Campinas, Brazil. The drying body of the flash dryer is 3 m long and the internal diameter 0.15 m, with an evaporative capacity of approximately 70 kg of water per hour. The air was impelled by a centrifugal fan at 1,200 m³h⁻¹ driven by a 5 HP electric pump at 1,750 rpm. The drying air heating unit consisted of a steam system with a nominal capacity of 38,400 kcal/h, enough to heat the air to 150 °C, plus an electrical resistance system with a nominal capacity of 46,000 kcal/h - the two systems installed in parallel, but operating independently. This heating unit allowed for the possibility of working in a wide range of air temperatures in automatic mode. A detailed description of this type of dryer and its functioning can be found in Perry et al. (1963).

Figure 1 shows the steps used in the drying of the okara in the flash dryer, including the stage of mixing the moist okara (83 g.100 g⁻¹ moisture content) with the "seed" in proportions from 26 to 74%, according to the Central Compound Rotational Design (CCRD), sufficient to achieve initial moisture levels between 26 and 61 g.100 g⁻¹, so as to establish the conditions to start functioning the flash dryer.

The "seed" or original okara, with 5 g.100 g⁻¹ moisture, was produced by drying the okara in a tray drier (65° C/8 h) to a moisture content of 5 g.100 g⁻¹, followed by grinding it in a model 740646 hammer mill (Treu & Cia Ltda., Rio de Janeiro, Brazil) with a ½ inch sieve, in order to reduce the particle size. Batches

of approximately 5 kg of the moist okara and "seed" mixture were used in the eleven drying trials of the CCRD.

In all trials, the levels of moisture in the initial mixture and in the samples removed at regular intervals during the drying process were determined, until final moisture content between 3 and 5 g.100 g⁻¹ was reached - this value being considered ideal in this case. The total drying time taken to reach the final moisture content was also noted.

In the continuous functioning regime, part of the dried residue returned through a recirculation valve to be reincorporated to the moist residue, allowing for continuous drying. The other part of the dried residue was collected for packaging. This procedure assured that the material entering the flash dryer had the moisture content required for the good functioning of the equipment. It should be noted that, for the initial start of the flash dryer, the "seed" could be substituted by some commercial flour such as manioc flour, for example.

2.5 Statistical design

A Central Compound Rotational Design (CCRD) was used, consisting of a 2² factorial design for 2 independent variables at 2 levels, a star design with four axial points at a distance of √2 from the central point and three repetitions at the central point (BARROS NETO; SCARMINIO; BRUNS, 2002). Table 1 shows the lower (-1) and upper (+1) levels fixed for each of the two
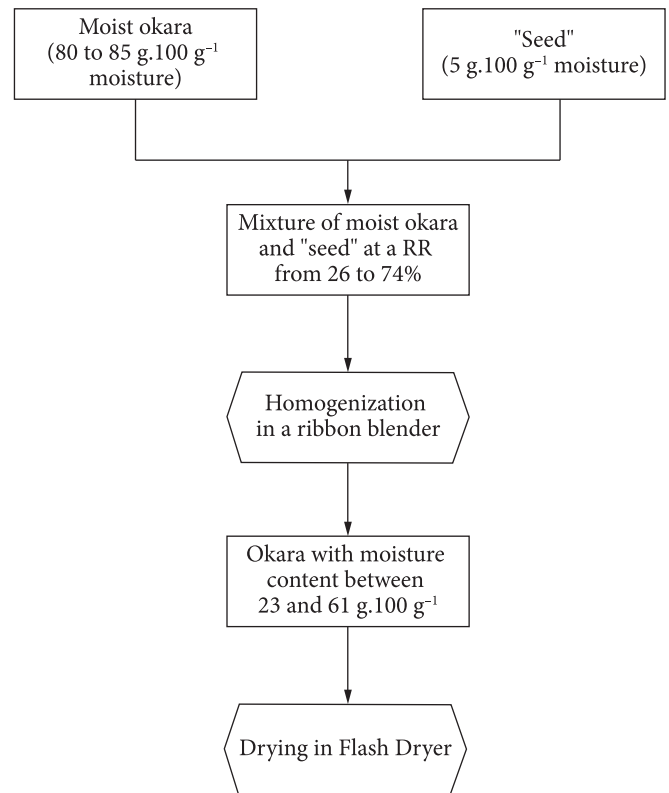

Figure 1. Basic flow diagram of the flash drying of okara, including the steps of mixing the moist okara with the "seed" at recirculation rates (RR) between 26 and 74%, according to the CCRD.

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Table 1. Independent variables and levels of variation used in the statistical central compound rotational design.

Variables	Code	Levels				
		$-\sqrt{2}$	-1	0	+1	$+\sqrt{2}$
Recirculation rate of the dried material (RR in %)	x_1	26	35	50	65	74
Drying air temperature (T °C)	x_2	252	260	280	300	308

independent variables studied: rate of recirculation of the dried material (RR in %) and temperature of the drying air (T in °C), codified respectively as x_1 and x_2, and also the lower $(-\sqrt{2})$ and upper $(+\sqrt{2})$ levels of the axial points for the same variables.

The responses or dependent variables studied were: initial moisture, final moisture after 120 seconds, protein, lipids, fiber, ash, carbohydrates, emulsifying capacity (EC), emulsion stability (ES), protein solubility (PS) and water holding capacity (WHC) in the eleven trials resulted from the CCRD, as shown in Tables 2 and 4.

2.6 Statistical analysis

The results of the physicochemical determinations and the technological functional properties obtained in the eleven trials corresponding to the proposed statistical design were used to fit the quadratic model and to calculate the experimental error according to response surface methodology (BARROS NETO; SCARMINIO; BRUNS, 2002), using the version 6 Statistica program. The quadratic model for the two variables can be represented as follows: (Equation 5)

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_{12} + \beta_{11}(x_1)^2 + \beta_{22}(x_2)^2 + \varepsilon \qquad (5)$$

where:

x_1 and x_2 are the coded variables, β_0, β_1, β_2, β_{12}, β_{11} and β_{22} are the parameters of the regression model, and ε is the experimental error.

These results were submitted to analysis of variance and to Tukey's test.

3 Results and discussion

3.1 Okara composition

Table 2 shows the physicochemical composition of the eleven residues dehydrated in the flash dryer according to the CCRD. The original okara (trial 12) was dehydrated in a tray dryer (65 °C/8 hours) to 5 g.100 g^{-1} moisture content, and the results are also presented in Table 2 to aid comprehension. The original okara, also named "seed", was used in proportions ranging from 26% to 74% according the CCRD, in mixtures with the moist okara (82.87 g.100 g^{-1} moisture content) to obtain materials with different moisture levels. The main objective was to verify the adequate initial okara moisture level for the functioning of the flash dryer.

The initial moisture contents of the residues in the eleven CCRD trials varied significantly ($p \leq 0.05$) - from 21 to 60 g.100 g^{-1}, significantly influencing the total drying time

required to obtain dehydrated okara with a final moisture content between 3 and 5 g. 100g^{-1} - value considered ideal in this work.

The trials including smaller proportions of tray dried okara RR = 26% (trial 5) and RR = 33% (trials 1 and 3) resulted in mixtures with higher initial moisture contents, 53 to 60 g.100 g^{-1} (wwb), requiring from 5 to 6 minutes of drying to reach 3 to 5 g.100 g^{-1} (wwb) final moisture content. The mixtures with equal proportions of moist and dry okara, RR = 50% (trials 7 and 11) presented moisture contents between 33 and 41 g.100 g^{-1} (wwb) and drying times of about 3 minutes to reach the desired moisture content. The trials with greater proportions of dry okara, RR = 67% (trials 2 and 4) and RR = 74% (trial 6) presented lower initial moisture contents (26 and 21 g.100 g^{-1} dwb) and dried in less than 2.5 minutes. Thus, it was concluded that it is possible to dry residues with initial moisture contents between 21 and 61 g.100 g^{-1} (dwb) in the flash dryer, although the total drying time can varry as a function of the initial moisture content of the residues.

The final moisture of the okara after 120 seconds was optimized through response surface methodology based on the following drying parameters: recirculation rate of the dry residue (RR) and drying air temperature (T). This period of time was selected because it was possible to determine the moisture content in all trials of the CCRD. The analysis of variance of the results for final moisture content after 120 seconds of drying indicated that the quadratic model fitted the experimental data (Table 3).The F tests for the regression (R) and lack of fit (lf) indicated that the regression was significant ($MQ_R/MQ_r = 13.14 > F_{(5,5)} = 5.05$) and the quadratic model did not present a lack of fit ($QM_{lf}/MQ_{pe} = 1.21 < F_{(3,2)} = 9.28$) at the 95% probability level. In addition, the percentage of variation explained by the model was 92.92%. The analysis of the effects indicated the significant terms: mean and x_1. The terms x_2 and the interaction $x_1 . x_2$ were non-significant at the 95% probability level, and the simplified mathematical equation could be represented by Equation 6, which satisfactorily described the response surfaces shown in Figure 2.

$$\hat{y} = 7.072_{\pm 1.653} - 7.924_{\pm 1.010} x_1 \qquad (6)$$

According to Equation 6, one can dehydrate okara in a flash dryer to 6 g.100 g^{-1} of moisture content ($\hat{y} = 6$) using the $x_1 = 0.135$ condition, which corresponds to RR = 51% in a drying time of 120 seconds, regardless of the drying air temperature, that is, within the 252 °C to 308 °C range studied in this work. The RR value equals to 51% could be extrapolated to the value of 40 g.100 g^{-1} initial moisture content of okara, calculated by the interpolation between the values of 33 and 67% of the RR and

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Table 2. Results[1] for the physical chemical determinations (responses) obtained for industrial okara dehydrated in a flash dryer according to the central compound rotational design (Trials 1 to 11) and for the original okara dehydrated in tray dryer (trial 12).

Trial	Real values		Drying time (s)	Initial moisture (g.100 g⁻¹ wwb)	Final moisture after 120 seconds of drying (g.100 g⁻¹ wwb)	Responses				
	RR (%)	T (°C)				Protein (Nx6.25) (g.100 g⁻¹ dwb)	Lipids (g.100 g⁻¹ dwb)	Fiber (g.100 g⁻¹ dwb)	Ash (g.100 g⁻¹ dwb)	Carbohydrates (g.100 g⁻¹ dwb)
1	33	260	385	53.07 ± 0.22 [c]	26.43 ± 0.24 [a]	39.61 ± 0.31 [c,e,f]	16.56 ± 0.08 [b,c]	17.32 ± 0.33 [ab]	3.72 ± 0.14 [b]	16.91 ± 0.38 [b,c,d]
2	67	260	128	26.82 ± 1.91 [f]	4.35 ± 0.11 [i]	40.13 ± 0.17 [d,f]	18.11 ± 0.34 [a]	15.69 ± 0.23 [bc]	4.09 ± 0.10 [a]	17.85 ± 0.16 [a,b,c]
3	33	300	285	56.03 ± 1.19 [c]	20.01 ± 0.15 [c]	38.25 ± 0.08 [e]	16.00 ± 0.02 [c]	15.54 ± 1.4 [bc]	3.78 ± 0.05 [b]	19.35 ± 1.25 [a,b,c]
4	67	300	140	26.41 ± 0.26 [f]	4.38 ± 0.06 [i]	41.43 ± 0.32 [b]	17.40 ± 0.43 [a,d]	15.78 ± 0.72 [ab,c]	4.03 ± 0.03 [a]	16.65 ± 0.70 [b,c,d]
5	26	280	303	59.76 ± 0.48 [b]	21.81 ± 0.11 [b]	40.50 ± 0.36 [b,c,d]	15.84 ± 0.09 [c]	15.46 ± 1.75 [bc]	3.76 ± 0.05 [b]	17.55 ± 0.26 [b,c,d]
6	74	280	180	21.17 ± 0.01 [g]	3.54 ± 0.07 [h]	41.01 ± 0.06 [b,d]	17.59 ± 0.36 [a,d]	17.91 ± 0.48 [ab]	4.09 ± 0.05 [a]	16.27 ± 0.53 [c,d]
7	50	252	175	32.60 ± 1.03 [e]	12.33 ± 0.17 [d]	34.93 ± 1.21 [g]	17.08 ± 0.25 [b,d]	16.12 ± 0.69 [a,b,c]	3.93 ± 0.05 [a,b]	21.43 ± 1.37 [a]
8	50	308	155	40.58 ± 0.32 [d]	7.95 ± 0.14 [f]	39.87 ± 0.28 [d,f]	17.46 ± 0.01 [a,d]	16.90 ± 0.33 [ab]	3.89 ± 0.02 [a,b]	15.80 ± 0.48 [c,d]
9	50	280	155	39.33 ± 0.18 [d]	10.11 ± 0.01 [e]	38.93 ± 0.55 [e,f]	16.99 ± 0.53 [b,d]	15.23 ± 0.7 [bc]	3.97 ± 0.14 [a,b]	19.03 ± 3.65 [a,b,c]
10	50	280	153	41.16 ± 0.13 [d]	6.63 ± 0.04 [g]	39.66 ± 0.54 [d,f]	17.37 ± 0.13 [a,d]	13.15 ± 0.7 [c]	3.88 ± 0.01 [a,b]	20.13 ± 0.32 [a,b]
11	50	280	180	40.97 ± 0.54 [d]	4.44 ± 0.10 [i]	40.95 ± 0.05 [b,d]	17.29 ± 0.36 [b,d]	17.98 ± 0.83 [ab]	3.95 ± 0.07 [a,b]	15.69 ± 1.11 [c,d]
12[2]	n.d.	n.d.	n.d.	82.87 ± 1.94 [a]	n.d.	43.93 ± 0.19 [a]	16.23 ± 0.46 [b,c]	19.17 ± 0.42 [a]	3.98 ± 0.16 [a,b]	13.94 ± 0.77 [d]

[1]Mean of three repetitions ± standard error; [2]Trial 12 → original okara dehydrated in tray dryer; The same letters in the same column do not differ significantly (p ≤ 0.05); n.d. = not determined.

Table 3. Analysis of variance for the fit of the quadratic model to the data from the results for the moisture content of the residue after 120 seconds in the flash dryer, according to the CCRD.

Factor	SS	df	MS	F
Regression (R)	607.5497	5	121.5099	13,1430*
Residues (r)	46.2262	5	9.2452	-
Lack of fit	29.8680	3	9.9560	1,2143
Pure error	16.3982	2	8.1991	-
Total	653.8159	10	-	-

% of the variation explained: 92.92%; *significant at 95% probability
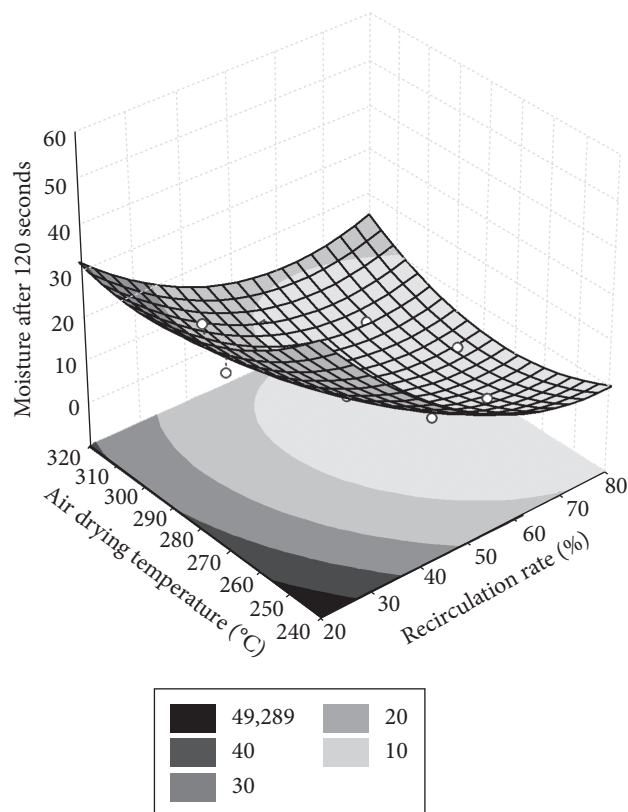
Figure 2. Response surface of the quadratic model for the response residue moisture after 120 seconds drying (y) as a function of the recirculation rate of the dried residue (x_1) versus the air drying temperature (x_2).

the respective average values of 54.5 g.100 g^{-1} and 26 g.100 g^{-1} of the initial moisture of the okara, extracted from Table 2. In other words, it is possible to obtain dried okara with 6 g.100 g^{-1} moisture from the okara with 40 g.100 g^{-1} moisture at 252 °C to 308 °C drying air temperatures. This results are supported by Tadano and co-workers (1981) cited by O'Toole (1999), who used a similar drying system to dry okara, containing initially 84.5% moisture and hot air (208-254 °C).

The protein content of the original okara (43.93 g.100 g^{-1} dwb) differed significantly (p ≤ 0.05) from the values obtained at the 11 trials, which ranged from 34.93 to 41.01 g.100 g^{-1} dwb. The analysis of variance showed evidence of a lack of fit for the quadratic model ($QM_{lack\ of\ fit}/QM_{pure\ error}$ = 9.62 > 3.41 = $F_{3,13}$) at

a 95% level of significance. However, all the linear (x_1, x_2) and quadratic (x_1^2, x_2^2) effects and the interaction ($x_1.x_2$) between the variables were significant (p ≤ 0.05). This indicated that the protein content varied as a function of the drying parameters: recirculation rate of the dried material, x_1, and drying air temperature, x_2, but in such a complicated way that it could not be explained by the mathematical model. The significant coefficients and respective standard errors of the regression parameters are showed in Equation 7.

$$y = 39.851 + 0.552\,x_1 + 0.640\,x_1^2 + 0.866\,x_2 - 1.025\,x_2^2 + 0.664\,x_1x_2 \quad (7)$$
$$\pm 0.2110 \quad \pm 0.129 \quad \pm 0.152 \quad \pm 0.129 \quad \pm 0.153 \quad \pm 0.182$$

Observing the pairs: trials 1 and 2, and trials 3 and 4 on Table 2, where the RR changes from low (-1) to high (+1) level, at constant air drying temperature, a tendency to increase the protein content was observed, respectively, 39.61 to 40.13 g.100 g^{-1} and 38.25 to 41.43 g.100 g^{-1}. Moreover, when observing the pairs: trials 1 and 3, and trials 2 and 4, where the air drying temperature changes from low (-1) to high (+1) level, at constant RR, the same tendency could be seen. The results of these observations confirm the complexity of the mathematical model with several significant effects on the protein content.

The contents of the other components, lipid (15.84 to 18.11 g.100 g^{-1} dwb), ash (3.72 to 4.09 g.100 g^{-1} dwb), fiber (13.15 to 17.98 g.100 g^{-1} dwb) and carbohydrates (15.69 to 21.43 g.100 g^{-1} dwb), obtained for the eleven residues dehydrated in the flash dryer according to the CCRD, were similar to those of the original okara (trial 12) and in agreement with values for residues from the soybean cultivars IAC 18, BRS 267 and BRS 232 studied by Grizotto et al. (2006). The analyses of variance for the values obtained for the lipid, fiber, ash and carbohydrate contents of the dried residues from the CCRD, indicated non-significant regression for the responses, with evidence of a lack of fit for the quadratic model. In addition, all the linear (x_1, x_2) and quadratic (x_1^2, x_2^2) effects, and the effects of the interaction ($x_1 . x_2$) between the variables of these responses were not significant (p ≤ 0.05). Based on these results, it can be affirmed that the physicochemical composition, except to protein, of the okara dehydrated in the flash dryer did not vary as a function of the drying parameters and remained similar to the mean values observed in the original residue (trial 12).

3.2 Technological functional properties

Table 4 shows the results for the technological functional properties of the products obtained in the 11 trials of the CCRD

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Table 4. Results for the technological functional properties (responses) obtained for industrial okara dehydrated in a flash dryer according to the central compound rotational design (Trials 1 to 11) and for the original okara dehydrated in a tray dryer (trial 12).

| Trial | Real values | | Technological functional properties | | | | | | EC[3] | ES[4] (%) |
| | RR (%) | T (°C) | WHC[1] (g H_2O g^{-1}protein) | | | PS[2] (%) | | | (mL oil.g^{-1} protein) | |
			pH = 3.00	pH = 5.00	pH = 7.00	pH = 3.00	pH = 5.00	pH = 7.00		
1	33	260	22.23 ± 3.73[a]	18.65 ± 0.83[a]	24.96 ± 2.53[a]	14.36 ± 0.00[d]	12.44 ± 0.48[d]	14.74 ± 0.53[f,g]	73.9	36.75 ± 14.01[b,c,d]
2	67	260	21.18 ± 1.75[a]	20.19 ± 2.02[a]	21.52 ± 0.66[a]	19.29 ± 0.53[b,c]	21.16 ± 1.06[a]	22.40 ± 0.70[b,c]	51.4	69.75 ± 0.82[a]
3	33	300	21.44 ± 0.08[a]	18.56 ± 4.79[a]	22.60 ± 5.80[a]	12.93 ± 0.55[d]	12.54 ± 0.00[d]	20.64 ± 0.00[c,d]	74.0	39.99 ± 9.16[a,b,c,d]
4	67	300	21.46 ± 4.08[a]	18.69 ± 0.20[a]	20.64 ± 4.49[a]	18.74 ± 0.51[b,c]	18.01 ± 0.51[b]	24.06 ± 0.51[b]	66.1	54.34 ± 9.14[a,b,c]
5	26	280	21.76 ± 4.72[a]	19.42 ± 3.42[a]	18.52 ± 3.54[a]	12.99 ± 0.52[d]	12.25 ± 0.52[d]	14.47 ± 0.52[g]	75.9	62.11 ± 3.73[a,b]
6	74	280	24.72 ± 4.07[a]	22.36 ± 3.09[a]	22.62 ± 6.37[a]	23.54 ± 0.51[a]	21.95 ± 0.69[a]	21.22 ± 0.34[c]	73.8	3.69 ± 0.36[e]
7	50	252	21.86 ± 5.14[a]	27.46 ± 7.96[a]	26.77 ± 7.87[a]	25.55 ± 0.80[a]	21.15 ± 0.60[a]	29.81 ± 1.20[a]	89.0	38.78 ± 5.48[a,b,c,d]
8	50	308	23.29 ± 4.29[a]	20.26 ± 5.23[a]	22.16 ± 2.14[a]	14.69 ± 0.53[d]	17.58 ± 0.00[b,c]	15.45 ± 0.53[f,g]	72.0	61.33 ± 13.12[a,b]
9	50	280	19.92 ± 0.61[a]	24.21 ± 4.29[a]	27.40 ± 1.94[a]	24.48 ± 0.00[a]	16.62 ± 0.55[b,c]	22.16 ± 0.00[b,c]	91.2	23.97 ± 4.69[c,d,e]
10	50	280	22.93 ± 0.97[a]	18.44 ± 4.01[a]	20.14 ± 1.62[a]	19.52 ± 0.53[b,c]	18.01 ± 0.53[b]	17.13 ± 0.71[e,f]	83.8	16.94 ± 6.54[d,e]
11	50	280	21.52 ± 3.11[a]	21.46 ± 2.92[a]	19.28 ± 4.31[a]	20.76 ± 1.03[b]	17.46 ± 0.52[b,c]	18.20 ± 0.52[d,e]	89.6	28.22 ± 8.78[c,d,e]
12[5]	n.d.	n.d	20.55 ± 1.17[a]	17.10 ± 5.26[a]	21.41 ± 4.76[a]	18.32 ± 0,48[c]	15.14 ± 1.13[c]	16.62 ± 0.96[e,f,g]	58.40	21.60 ± 7.09[c,d,e]

[1]WHC = Water Holding Capacity, mean of three repetitions ± standard error; [2]PS = Protein Solubility, mean of three repetitions ± standard error; [3]EC = Emulsifying Capacity, only one determination; [4]ES = Emulsion Stability, mean of three repetitions ± standard error; [5]Trial 12 → original okara dehydrated in a tray dryer; The same letters in the same column do not differ significantly (p ≤ 0.05); n.d. = not determined.

(Trials 1 to 11) and of the original okara (Trial 12), dehydrated in a tray dryer.

The Tukey's test for the results of the Water Holding Capacity (WHC) of the residues dehydrated in the flash dryer showed non-significant variation ($p \leq 0.05$): from 18.5 to 27 g $H_2O.g^{-1}$protein at the pH values of 3, 5 and 7. Trials 7 and 9 showed the highest values for WHC, above 27 g $H_2O.g^{-1}$protein, at the pH values of 5 and 7. The original dehydrated okara (trial 12) showed a WHC between 17 and 21 g $H_2O.g^{-1}$protein in the same pH range, within the same variation obtained for the residues dehydrated in the flash dryer, but well above the values of 13, 11 and 9 g $H_2O.g^{-1}$protein found by Buso et al. (2008) at the same pH values for commercial texturized soybean protein. The ANOVA for the WHC results at these pH values showed no lack of fit for the quadratic model, but no significant linear or quadratic term. In other words, the WHC is not affected by drying conditions, both in a pneumatic flash dryer with high performance (3 to 6 minutes at 252 to 308 °C) as well as in a tray dryer for long time (8 hours) and low temperature (65 °C). The variation in the soluble protein contents (PS) of the residues dried in the flash dryer (trials 1 to 11) was from 13 to 30% at the pH values of 3, 5 and 7, and it was significant at the 95% probability level. The ANOVA for the PS results at pH values of 3, 5 and 7, indicated some influence of the variables RR and air drying temperature with significant linear and quadratic terms for each of the responses. However, no mathematical model could be established for protein solubility, since evidence of a lack of fit was found at all the studied pH values. The highest value for soluble protein of 29.81% was found in trial 7 at pH 7, significantly ($p \leq 0.05$) above the value obtained for the original okara (16.62%) at the same pH. On the other hand, the protein level of trial 7 (34.9 g.100 g^{-1}) was significantly ($p \leq 0.05$) below compared to the original okara (43.9 g.100 g^{-1}), but comparable to that found by Ma et al. (1999) in commercial soy protein isolate (Supro 610) with less than 80% protein. This suggests that the primary structure of protein in okara was unfolded by heat during flash drying to a more soluble form, according to Wolf and Cowan (1975), and this resulted in an improved quality of the protein in the okara when evaluated for its solubility. The emulsifying capacity (EC) and emulsion stability (ES) express the emulsifying properties of the protein present in the okara. The best material is the one that shows high emulsifying capacity with good emulsion stability. One property isolated from the other does not result in good material.

The analysis of variance of the ES results indicated some influence of the air drying temperature with significant linear term. In fact, according Voutsinas, Cheung and Nakai (1983), the heat treatment seemed to impair the emulsifying capacity and stability of proteins. The F test indicated evidence of a lack of fit ($QM_{lack of fit}/QM_{pure error} = 25.397 > 3.41 = F_{3,13}$) for the quadratic model at a 95% level of significance, and no mathematical model could be established. The Emulsifying Capacity (EC) was carried out in single duplicate and, therefore, the results could not be submitted to analysis of variance.

The material obtained from trial 5 showed the capacity to produce emulsion (EC = 75.9 mL oil.g^{-1}protein) with good stability (ES = 62%). This material (trial 5), which showed a high protein level (40.41 g.100 g^{-1} dwb) with low soluble protein

content (12 to 14%) and intermediate lipid content (16 g.100 g^{-1} dwb), was dehydrated using the lowest recirculation rate of the dried residue (RR = 26%) and intermediate drying air temperature (T = 280 °C). Under this condition, the desired moisture content (6 g.100 g^{-1} wwb) was reached in 303 seconds. The good performance of the technological functional properties EC and ES made the material obtained from trial 5 interesting for the production of stuffed meat products such as frankfurters, since those technological functional properties are of special importance in this class of product. The product obtained from trial 8 also showed potential for the production of such stuffed meat products. That residue showed a protein content of about 39 g.100 g^{-1} (dwb), a high value for EC (72 mL oil.g^{-1}protein) and good stability (61%) and water holding capacity (22 gH_2O.100 g^{-1}), in spite of its low soluble protein content (15 to 17%) at the pH values of 3, 5 and 7. The okara from trial 7 (RR = 50%, $T_{drying air}$ = 252 °C) dried in 175 seconds and presented an intermediate protein content of 35 g.100 g^{-1} (dwb), but it was the product that showed the best results for WHC of 27 g $H_2O.g^{-1}$protein at pH values of 5 and 7, and a higher PS value of 30% at pH 7. This material presented good EC (89 mL oil.g^{-1}protein), but low stability (39%). Thus, the material obtained from trial 7 could be indicated for the formulation of products where the water holding capacity is the most important characteristic, for instance, in confectionary products. The findings from trial 7 were in agreement with Ma et al. (1999), who considered that the emulsification of protein is influenced by solubility and surface hydrophobicity, and the higher emulsion stability in the okara protein isolates may be due to the higher solubility of the protein. Contradictorily, the results from trials 5 and 8, with high EC but low PS value, are the opposite of the relationship between the emulsifying properties of the proteins and its solubility, as established by Ma et al. (1999). The okara dehydrated in the tray dryer (Trial 12) showed WHC and PS results within the range of variation observed for the eleven trials of the CCRD. All the same, the values obtained for the Capacities to Emulsify (EC) and Stabilize Emulsions (ES) were below the levels obtained in the materials from trials 1 and 3, whose materials only contained 33% of okara dehydrated in a tray dryer. Therefore, one could conclude that drying okara in a tray dryer (65 °C/8h) harmed the quality of the protein regarding its capacity to produce stable emulsions. This damage was minimized when the RR of the dry residue was equal or smaller than 50%.

4 Conclusions

Based on the results obtained, it was concluded that it is technically feasible to dry soymilk residue in a flash dryer. It is possible to dehydrate residues with initial moisture contents between 21 and 61 g.100 g^{-1}, although the higher the initial moisture content of the residue, the longer the drying time.

The proximate concentration of the okara was not altered by the drying parameters used in this work, considering that the protein (36.36 to 41.39 g.100 g^{-1} dwb), lipid (13.19 to 16.52 g.100 g^{-1} dwb), fiber (21.43 to 43,74 g.100 g^{-1} dwb), ash (3.61 to 4.59 g.100 g^{-1} dwb) and carbohydrate (38.91 to 45.01 g.100 g^{-1} dwb) contents of the products obtained from the

eleven trials of the CCRD were similar to those found in the original residue dried in a tray dryer (65 °C/8 hours).

Response Surface Methodology (RSM) showed that, for an 120-second drying cycle, the lower the moisture contents ($\hat{y}$) obtained in the residue, the higher the recirculation rate (x_1), regardless of the drying air temperature (x_2), as expressed by the equation $\hat{y} = 7.072 - 7.924x_1$, with $R^2 = 92.92\%$.

The recirculation rate of the dry residue (RR), or x_1, was preponderant over the air drying temperature (T), or x_2, considering that, from the analysis of variance, the terms x_2 and $x_1.x_2$ were non-significant at the 5% level of probability.

Based on the drying parameters used for the flash dryer, optimized by RSM, one can obtain residues with 6% moisture content (dwb) using the condition for $x_1 = 0.135$, corresponding to a RR = 51%, with a drying cycle of 120 seconds and $T_{drying\ air}$ = 252 °C to 308 °C.

The okara dried in flash dryer presents potential as food ingredient, and it could be indicated for the production of stuffed meat products, such as frankfurters, or confectionary products, based on its results for technological functional properties.

In general, it can be stated that the drying of okara in a tray dryer (65ºC/8h) harmed the quality of the protein with respect to its capacity to produce stable emulsions. This damage could be minimized by using a RR of the dry residue equal or smaller than 50%.

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