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Research Article

Application of the Response Surface Methodology to Obtain Pumpkin (*Cucurbita moschata*) Powder through Spray Drying

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Abstract: The optimization of the process parameters was the aim of this study to obtain a powder from the pumpkin juice (*Cucúrbita moschata*) using the spray drying method. For the optimization of spray drying a surface response methodology was used, considering a central design composed of three factors: Maltodextrin concentration (10-25%), the temperature of the air inlet (150-170°C) and feed flow rate (4000-5000 mL/h) and the response variables evaluated to determine the optimal conditions of the process were: powder yield, humidity, hygroscopicity and solubility of the powder. The results of the statistical analysis indicate that all factors significantly affected the response variables, an increase in the addition of maltodextrin concentration to the pumpkin juice flow, generates an increase in yield, solubility and lower hygroscopicity values, the increase of the inlet temperature and the feed flow rate produced a decrease in the moisture content of the obtained powder. The optimal conditions of the process were reached with a 25% of maltodextrin concentration, 170°C for the air inlet and a flow rate of 4000 mL/h. These process parameters, allow obtaining a powder with a yield of 62.70%, humidity 3.40%, hygroscopicity 28.70% and solubility 71.5%, indicating a technological opportunity to generate and economic value to the pumpkin fruit, which allows improving the life quality of the country's farmers.

Keywords: Microencapsulation, microstructure, pumpkin (*Cucurbita moschata*), spray drying

INTRODUCTION

Pumpkin (*Cucúrbita moschata*) is an annual herbaceous plant of the *Cucurbitaceae* family. It is one of the most important vegetables in global agricultural systems (Maran *et al*., 2013). In Colombia, it is cultivated non-intensively in association with some legumes and it is used in the preparation of typical dishes and to obtain food products nutritionally rich in fats, carbohydrates and minerals (Zhang *et al*., 2000), dietary fiber and vitamins (Nawirskan *et al*., 2009), important components that provide beneficial effects for human health (Wang *et al*., 2012).

Spray drying is characterized by its rapid water evaporation and short drying time, which are characteristics that allow it to diminish thermal damage and loss of nutrients. It has been used to obtain good quality powders from tomato juice (Goula and Adamopoulos, 2005), white carrot (Ersus and Yurdagel, 2007), watermelon (Solval *et al*., 2012), eggplant (Arrazola *et al*., 2014), cantaloupe (Oberoi and Sogi, 2015) of easy distribution and storage at room temperature for long periods, without compromising its stability (Jayasundera *et al*., 2011). The physical-chemical properties of the powders obtained through spray drying depend on some variables of the process, like a concentration of the encapsulating agent in the feed mix, air intake temperature and feed flow (Tonon *et al*., 2008).

Spray drying is affected by the viscosity and hygroscopicity of the solutions fed to the drying equipment, given the presence of sugars and acids of low vitreous transition temperature that allow the particles to adhere to the wall of the drying chamber, producing a low yield process. These problems can be solved by adding encapsulating agents of high molecular weight, like proteins, maltodextrin and gums with high vitreous transition temperatures (Caliskan and Dirim, 2016). No publications report on the parameters to obtain pumpkin powder; hence, the aim of this research was to optimize the parameters of the drying process through spray drying to obtain quality pumpkin powder with desirable characteristics.

MATERIALS AND METHODS

Raw materials: Fresh pumpkin with an acceptable degree of ripeness and horticultural quality, acquired in

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the local market in the city of Armenia, Colombia. These were washed, had the seeds and the skin removed and was cut into pieces in an electric mixer (Thermomix Tm 21) by adding distilled water in 1:3 proportion during the 60 sec and constant velocity of 7000 rpm and then filtered. The pumpkin juice obtained was mixed with different concentrations of maltodextrin Equivalent in Dextrose (DE) 19-20 (Shandong Boalingbao Biotechnology Co Ltd) in 9:1 ratio (p/p) The mixture was sonicated by using an ultrasonicator (Model WU-04711-70, Cole-Parmer Inc., Vernon Hills, IL, USA) fitted with a 22-mm tip diameter for 10 min in an ice bath at 4°C. The resulting pumpkin juice mixture with maltodextrin was spray dried, as described ahead.

Drying process and optimization: The spray drying process was carried out in an SD-06 Labplant drier (United Kingdom) at pilot plant scale basically composed of a feed system for the liquid, an atomizing device, an atomizing chamber and a powder collector system. The equipment operates with an airflow of 30 m^3/h, air evaporation rate of 1.5 L/h) with the counter flow.

The response surface methodology obtained the optimal level of the independent variables considering a central compound design that generated 16 combinations of experimental tests (Table 1) analyzed in the Statgraphics Centurion XVII software and with Analysis of Variance (ANOVA) with 95% significance level. The factors optimized were the Maltodextrin (MD) concentration, air intake Temperature (TE) and feed Flow rate (VF), which varied between 10 and 25%, 130-150°C and 400-600 mL/h, respectively. The response variables optimized to obtain the best quality characteristics of the pumpkin powder were the efficiency of the process (%), humidity (%), hygroscopicity (%) and solubility (%). The regression analysis was solved with a second-order polynomial model, according to Eq. (1):

$$Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} X_i^2 + \sum_{i=1}^{k-1}\sum_{j=2}^{k} b_{ij} X_i X_j \quad (1)$$

where,

Y	: The response
X_i and X_j	: Variables (i and j range from 1 to k)
β_0	: The model intercept coefficient
β_j, β_{jj} and β_{ij}	: Interaction coefficients of linear, quadratic and the second-order terms, respectively
k	: The number of factors (k = 3 in this study) and is the error (Maran *et al*., 2013)

Finally, the pumpkin powder samples obtained were weighed, placed in tightly sealed bags and stored in desiccators until their further analysis. The output in weight obtained after drying through atomizing was calculated from the determinations of the weight of the powder obtained, according to Eq. (2):

$$\text{Yield } (\%) = \frac{\text{grams powder obtained}}{\text{grams product fed}} 100 \quad (2)$$

Humidity content: Water content was quantified via the AOAC 925.10 gravimetric method: A 2-g sample was dried in a hot-air furnace at 103°C during 1 h and loss of humidity was determined by weighing and comparison of the weight of the sample before and after drying (AOAC, 2005).

Hygroscopicity: One gram of powder was placed in a Petri dish at 25°C and introduced into a chamber containing a saturated NaCl solution (75.4% relative humidity). After 1 week, the samples were weighed and results were expressed as grams of humidity/100 g of dry solids (g/100 g) (Cai and Corke, 2000; Ersus and Yurdagel, 2007).

Solubility: One gram of powder was added to 100 mL of distilled water, which was agitated manually until solubilizing the entire sample and centrifuged at 3000 rpm for 10 min. A representative sample of 25 mL of the supernatant was taken and transferred to a Petri dish. Finally, the sample was dried in a drying oven at 105°C for 5 h. Solubility (%) is calculated by weight difference (Ochoa *et al*., 2011).

Morphological characterization: This characterization was performed by using Scanning Electron Microscopy (SEM) in which the product is placed on the SEM slide using double-sided adhesive tape (Nisshin EM, Tokyo, Japan) and analyzed at an accelerating voltage of 20 kV after Pt-Pd sputtering by using an MSP-1S magnetron sputter coater (Soottitantawat *et al*., 2005).

RESULTS AND DISCUSSION

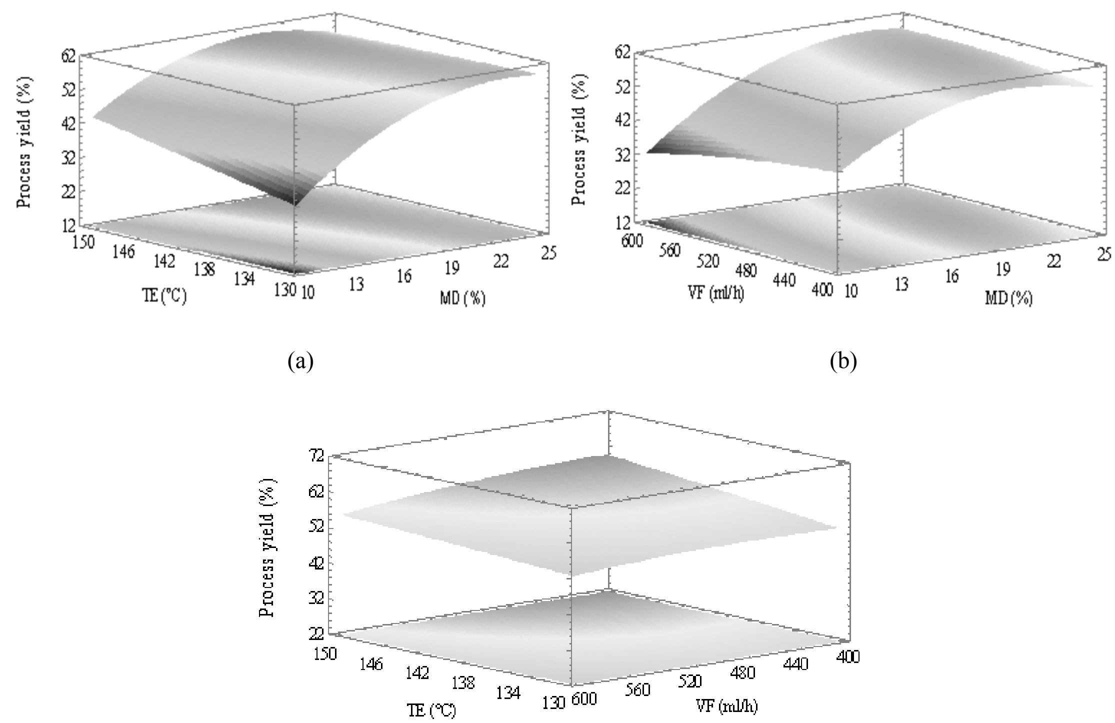
The yield process values, humidity content, hygroscopicity and solubility for each experimental trial are presented in Table 1 shows. The graphic representation of each response is presented in simultaneous function of both independent variables according to their importance for the response. The graphics for the process yield, humidity content, hygroscopicity and solubility in function of the variables (concentration of MD, TE and VF are shown in Fig. 1 to 4).

Characterization of pumpkin powder:

Process yield: The influence of the independent variables over the yield during the spray drying process is presented in Fig. 1 shows. The independent variables displayed a significant effect on the process yield. Increased TE increased the process yield, which may be attributed to higher heat and mass transfer efficiency at high temperatures.

Table 1: Experimental design for spray drying runs with their corresponding response values

Factors				Response variables			
Rum	MD (%)	TE (°C)	VF (mL/h)	Yield (%)	Humidity (%)	Hygroscopic (%)	Solubility (%)
1	17.50	140.00	668	51.00	3.15	23.13	58.29
2	17.50	140.00	500	56.57	3.28	24.32	60.89
3	4.88	140.00	500	16.87	2.26	33.86	48.41
4	17.50	140.00	332	58.65	2.72	26.40	63.09
5	10.00	130.00	400	32.88	3.00	27.65	54.41
6	25.00	130.00	600	59.29	2.82	20.82	65.86
7	10.00	130.00	600	26.97	3.01	27.44	52.41
8	17.50	156.81	500	61.03	3.14	26.37	62.69
9	17.50	123.18	500	54.00	3.51	23.83	59.78
10	30.11	140.00	500	49.86	2.16	20.21	70.11
11	10.00	150.00	600	37.80	2.82	30.08	56.36
12	10.00	150.00	400	47.21	2.37	31.59	57.88
13	25.00	150.00	600	56.29	2.52	22.95	67.94
14	25.00	150.00	400	54.40	2.45	24.20	68.82
15	17.50	140.00	500	56.37	3.25	24.32	60.22
16	25.00	130.00	400	53.97	2.45	22.15	63.70



(a) (b) (c)

Fig. 1: Effect of MD concentration, TE and VF on process yield

Similar effects were observed by Ersus and Yurdagel (2007), Solval *et al*. (2012), Silva *et al*. (2013) and Muzaffar and Kumar (2015) and in drying through atomizing of carrot, cantaloupe, jaboticaba and tamarind juice, respectively. In addition, when using high VF, the powder's humidity content diminished upon combining a high drying temperature at the input and low output temperatures, which increased the amount of water evaporating from the product (Tonon *et al*., 2008) the yield process, humidity content and solubility had significant differences in the concentration of MD added to the feed juice; an increased concentration of MD in feed juices to the drying process produced an increased yield of the powder obtained (Bhusari *et al*., 2014). Also, reduction of VF at lower concentrations of MD diminishes the yield obtained, given that higher amounts of the product remain adhered to the internal walls of the drying chamber (Largo-Avila *et al*., 2015).

Humidity content: The effect of the process´s variables on the humidity content of the pumpkin powder is shown in Fig. 2a to 2c. The humidity content was significantly influenced by the concentration of MD, TE and VF. An increase in TE leads to a decrease in the humidity content of the powder samples that may be due to a higher temperature gradient between the atomized feed and the drying medium, causing rapid water elimination and obtaining powders with low humidity content. Similar results were obtained by Quek *et al*. (2007) in watermelon juice and by Abadio *et al*. (2004) in pears. The VF revealed a positive effect on the powder's humidity content. Increased VF produces shorter contact times between the feed flow and the drying medium, which leads to less-efficient heat transfer and lesser water evaporation. Tonon *et al*. (2008) and Chegini and Ghobadian (2005) found similar results in drying through pulverization of acai pulp and orange juice, respectively.

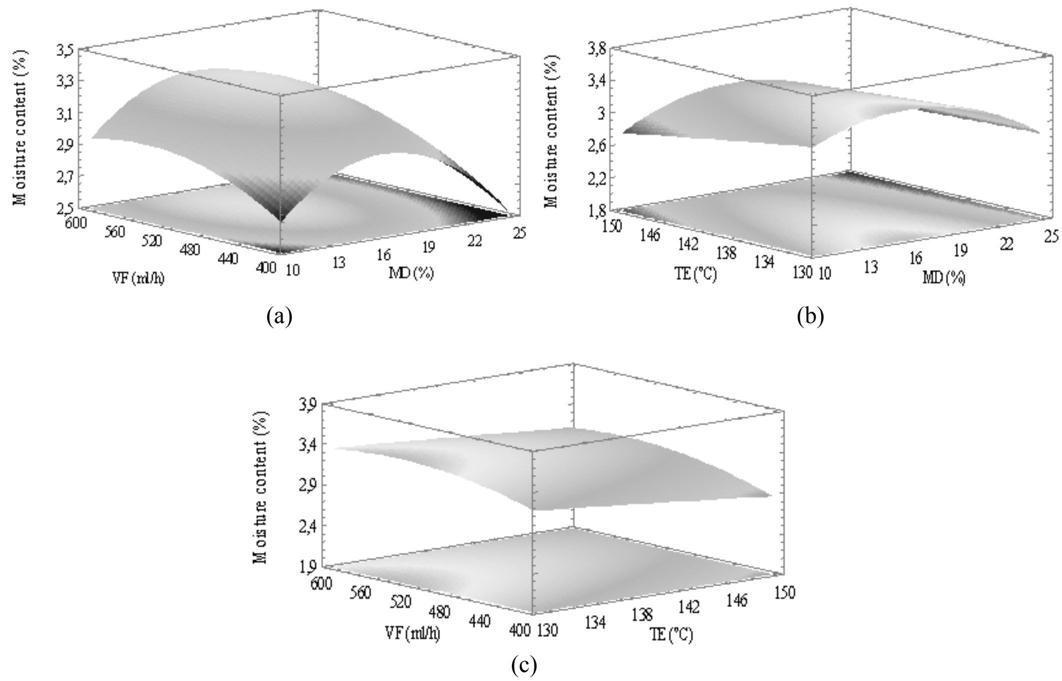


Fig. 2: Effect of MD, TE and VF rate on moisture content

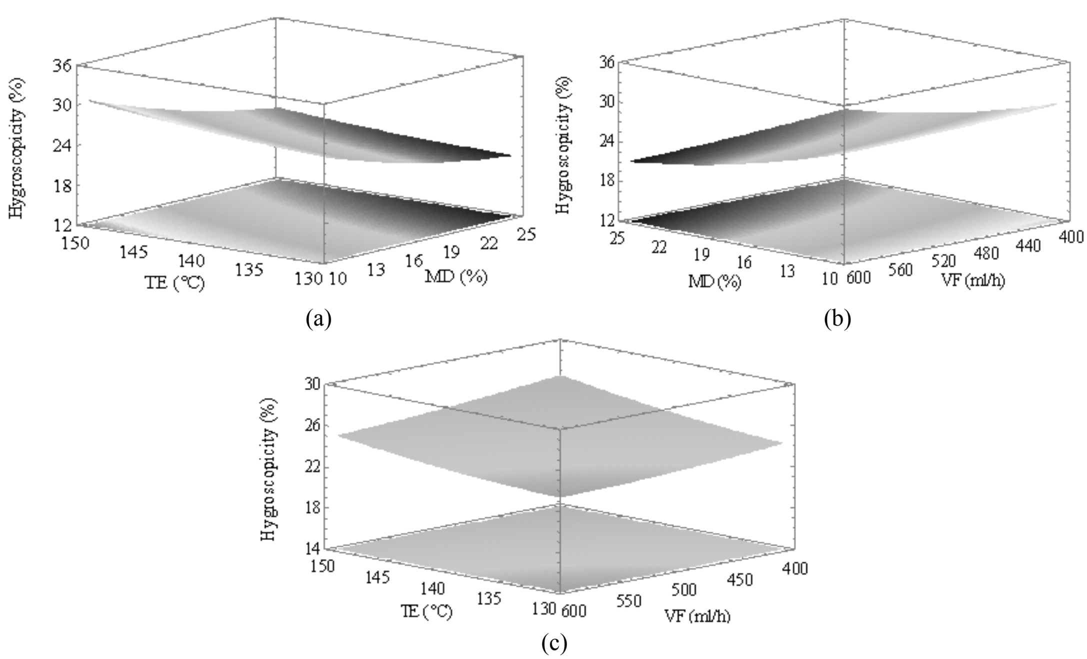


Fig. 3: Effect of MD, TE and VF on hygroscopicity

Hygroscopicity: Figure 3a to 3c shows the influence of independent variables upon the hygroscopicity of the pumpkin powder. The lowest hygroscopicity values were obtained with a higher concentration of MD that may be due to the lower hygroscopicity of the MD, confirming its effectiveness as the encapsulating agent. (Bhusari *et al*., 2014). The feed VF and the TE also influenced the hygroscopicity of the powder samples. Increased VF and diminished TE decreased the hygroscopicity of the powders; this shows that higher humidity content of the powder samples means their lower concentration of water and the lower gradient between the powder sample and the surrounding air. Goula and Adamopoulos (2008) and Rubian *et al*. (2015) reported similar results in spray drying of tomato and lemon pulp, respectively.

Solubility: Figure 4a to 4c illustrates the effect of the independent variables on the solubility of the powder samples. All the process variables showed a significant effect on the solubility of the powders. The MD and TE concentrations showed a significant positive effect on the water solubility of powder samples. The highest solubility values were obtained at a higher MD concentration. Instantaneous solubility is directly related to the powder's microstructure. A larger amorphous Surface means the powder will have greater water solubility; inversely, the presence of particles in crystalline state yield a lower solubility (Cano-Chauca *et al*., 2005; Caparino *et al*., 2012). Likewise, diminished solubility was noted with increased VF due to the effect it has on the humidity content (Bhusari *et al*., 2014).

Morphological characterization of the pumpkin powder: Figure 5 shows the morphology of the pumpkin powder obtained using the optimum conditions of the process. The increased drying temperature produced a greater number of particles with smooth and spherical surfaces, this behavior is attributed to the increase in the differences in the speed of drying, which cause a more rapid evaporation of water and the formation of smooth surfaces (Tonon *et al*., 2008). Additionally, the study observed particles of different sizes with rough surfaces, which is typical in a spray drying process (Rubiano *et al*., 2015). Similar results of microencapsulated with maltodextrin have been observed in extracts of mango and black carrot pigments (Caparino *et al*., 2012; Ersus and Yurdagel, 2007).

Optimization: The optimization of the parameters of the spray drying process was carried out on the pumpkin powders to obtain the criteria desired for each response. The independent variables were kept within the range, while the yield and solubility response variables were maximized and the humidity content and hygroscopicity response variables were minimized based on the desirable characteristics of the pumpkin powder. The results revealed that a product with the following conditions of process yield at 62.70%, humidity content at 3.40%, hygroscopicity at 28.70% and solubility at 71.5%, respectively, may be obtained by operating the drier through spraying with MD concentration at 25%, air input temperature of 170°C and feed flow rate of 400 mL/h.

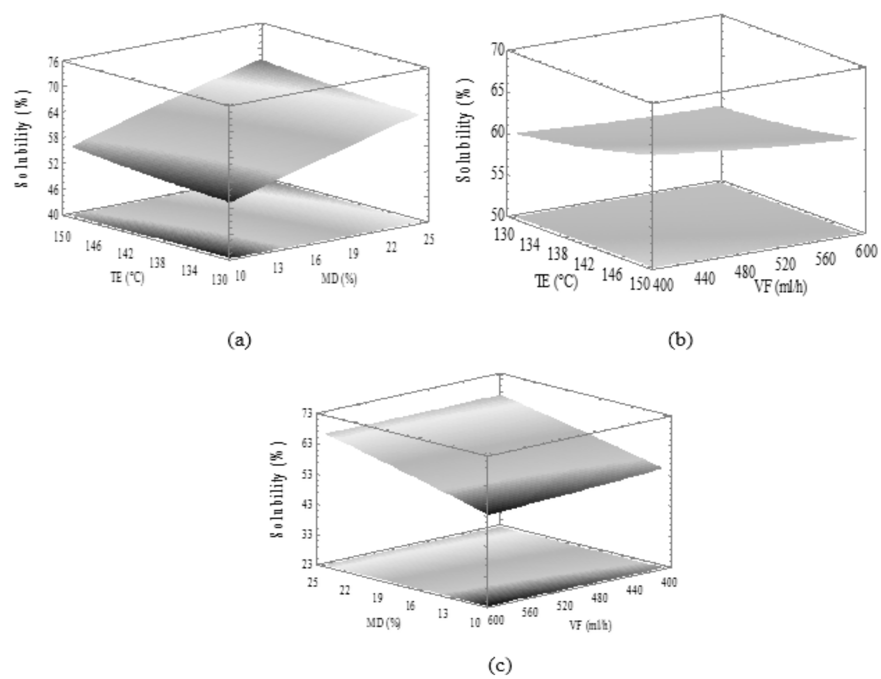


Fig. 4: Effect of MD, TE and VF on solubility

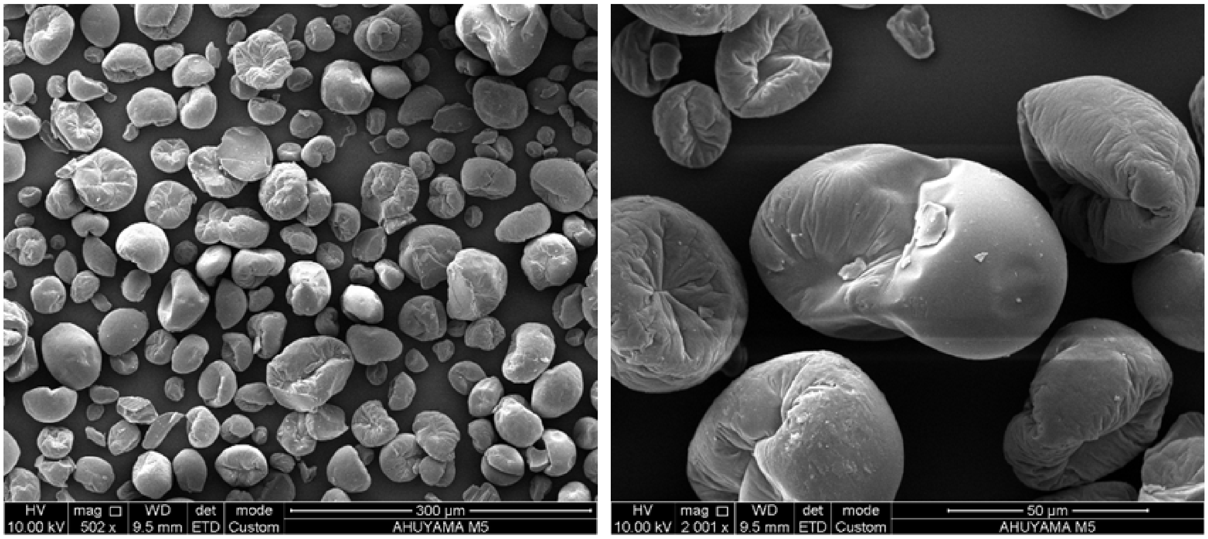


Fig. 5: Scanning Electron Microscopy (SEM) of the pumpkin powder

CONCLUSION

A spray drying process is a technological tool that provides added value to pumpkin, by increasing its useful life, ease of transport and commercialization. These characteristics have turned the pumpkin into an important raw material for the preparation of soups and typical dishes at industrial and domestic levels. Experimental optimization of the spray drying process allows the improvement quality attributes of the powdered products, providing economic value, improving the life quality and food and nutrition safety of the country's farmers.

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