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Optimization of spray-drying parameters for mature acerola powder production

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Abstract

Response surface methodology was used to optimize inlet air temperature and maltodextrin 10 DE content on spray drying mature acerola pulp. The inlet air temperatures were 150, 170, and 190°C, while maltodextrin contents were 50.0, 58.4, and 66.7% wb based on the feed solids (1:1, 1:1.5, and 1:2 pulp:maltodextrin wb proportions, respectively). Process yield, moisture content and ascorbic acid retention of powders were evaluated. The optimal conditions to produce acerola powder were 144°C for inlet air temperature and 66.7% wb based on the feed solids for maltodextrin content. With these conditions 81% process yield, 4.2% wb moisture content and 91.2% ascorbic acid retention were achieved. The powder obtained with the optimized parameters showed semispherical particles and an average particle size of 16.3 µm by using SEM, whereas the results showed a good sensory acceptance when it was applied to an ice cream.

Keywords: *Acerola, spray drying, optimization, process yield, moisture content, ascorbic acid retention.*

1. INTRODUCTION

Acerola (*Malpighia emarginata* DC) is a tropical fruit believed to be indigenous to Central America that has spread to many other tropical and subtropical regions. This small red fruit, which is also called Barbados cherry, West Indian cherry, French cherry, or native cherry (Delva and Goodrich-Schneider, 2013a), has an important agroindustrial potential due to its high vitamin C content and phytochemicals with high biological activity (Alves et al., 2008; Mezadri et al., 2008; Delva and Goodrich-Schneider, 2010, 2013b; Freire et al., 2013; Ribeiro da Silva et al., 2014).

Although fresh consumption is limited because its limited shelf life, acerola has a high pulp yield, enabling the production of concentrated pulps, jams, jellies, ice creams, and fruit syrups (Delva and Goodrich-Schneider, 2013a). In this context, drying of the fruit pulp represents an attractive economic approach to produce food products for maintaining health and preventing degenerative diseases, as well as extending conservation.

Spray drying is commonly used in the food industry because it is an economic and fast process in which a liquid feed solution is converted into powder (Shishir and Chen, 2017). Spray dried acerola powders have been studied earlier (Righetto and Netto, 2005; Moreira et al., 2009; Brito et al., 2010; Rezende et al., 2018). However, in those studies only immature pulp, industrial pomace or residues extracts were evaluated. In addition, only in the works of Moreira et al. (2008, 2009) the response surface methodology was applied to optimize the spray drying of acerola pomace, but with high inlet air temperatures, which may cause powder stickiness.

Therefore, response surface methodology was used to find the optimum inlet air temperature and maltodextrin content for spray drying mature acerola pulp to achieve high process yield and ascorbic acid retention as well as low moisture content.

2. MATERIALS AND METHODS

2.1. Materials

Ripe acerola fruits, selected by the typical red color and soft texture, were provided by a plantation in Alquízar, Cuba in September 2019. The process to produce the pulp with 6% wb soluble solid content involved selection of the fruits, washing in chlorinated water, pulped and sieved (60-mesh), pasteurized at 90°C for 12 min, packed in 10 kg polyethylene bags, and stored at -2°C. Maltodextrin DE 10 (IMSA, Guadalajara, Mexico) was used as carried material.

2.2. Spray drying

Drying was done in a lab-scale spray dryer (SD-05, Lab-Plant Ltd., Huddersfield, England). Based on preliminary studies (Cuevas-Glory et al., 2017; Aragüez-Fortes et al., 2019), the processing parameters were 0.7 mm injector nozzle, drying air inlet flow rate 63 m^3/h, feed flow rate of 0.52 L/h and outlet air temperature 75 ± 5°C. The inlet air temperatures examined were 130, 150, and 170°C and maltodextrin contents were 50.0, 58.4, and 66.7% wb based on the feed solids (1:1, 1:1.5, and 1:2 pulp:maltodextrin wb proportions, respectively). A total of 200 g of feed solution was processed in each run. The product was recovered from the spray dryer, packed in polyethylene bags, and conserved in a desiccator at 25°C until analysis.

2.3. Powder analysis

Spray-drying yield was calculated by the total mass of recovered powder and feed mass (dry basis) ratio according to Aragüez-Fortes et al. (2019). Moisture content was determined at 105 °C by a thermobalance Sartorious MA35 (Gottingen, Germany). Ascorbic acid was determined by the 2,6-dichlorophenolindophenol method (AOAC, 2019) and the result was expressed as ascorbic acid retention based on its concentration before and after drying, and considering the moisture content of the powder.

Morphology of the powder produced with the optimized parameters was observed in a scanning electron microscope (5130 SB, Tescam, Prague, Czech Republic) operated at 10 kV. Particle diameters were determined from 100 particles of four images obtained at 2000× magnification. Average particle size D43 was calculated with these data (Zotarelli et al., 2017).

2.4. Sensory analysis

The acceptance of the acerola powder produced with the optimized process was assessed by a sensory evaluation with 100 non-trained consumers (68% females, 22–55 age range), using a hedonic scale ranging from 1 (I dislike very much) to 5 (I like very much) according to ISO 11136 (2014). The room in which analyses were done was odorless, uniformly illuminated and at 22 °C. The powder was evaluated in an ice cream with 10% wb acerola powder. This concentration was fixed after some preliminary experiments.

2.5. Response surface methodology

RSM was used to investigate the influence of process parameters on process yield, moisture content and ascorbic acid retention, and draw the response surface plots. A 2-factor-3-level design with four replicates at the center point was selected using Design-Expert 8.07 (Stat-Ease Inc., Minneapolis, MN). Inlet air temperature and maltodextrin in feed dry solids were considered as the independent variables. The second-order polynomial models were assessed by the analysis of variance, determination coefficients and test for the lack of fit. Numeric and graphical optimisation were made to find a point set with the minimum moisture content and maximum process yield and ascorbic acid retention for these response variables.

3. RESULTS AND DISCUSSION

3.1. Experimental design

The process yield, moisture content and ascorbic acid retention are shown in Table 1. Regression models fitted to experimental results are shown in Table 2. In all the polynomial regressions the F-model were highly significant and the lack of fit F-values were not significant. The determination coefficients (R^2) were high, but they can be artificially inflated by simply continuing to add terms to the models, even if the terms are not statistically significant. The predicted R2 values agreed with the adjusted R^2 values, because both issues should be within 0.2 of each other. Adequate precisions (signal to noise ratio) were over four, which is the accepted limit. Therefore, the fitted models were suitable to assess the response variables as function of the selected factors.

3.2. Process yield

The process yields for acerola powders varied from 60.2 to 81.5% (Table 1). Slightly lower yields were reported by other researchers: 30–55% for guava pulp (Shishir et al., 2014), 16.0–31.6% for pineapple pulp (Wong et al., 2015) and 42.6–70.2% for guava pulp (Aragüez-Fortes et al., 2019), but close to 41.3–54.6% for beetroot juice (Bazaria and Kumar, 2016), 60.2–81.2% for bayberry juice (Liu et al., 2017) and 34.0–80.6% for orange juice (Pino et al., 2018), all them processed by the same technique.

The inlet air temperature and maltodextrin content significantly affect process yield (Table 2), with a major contribution by the maltodextrin content. The increased inlet air temperature led to lower yield, although a maximum is appreciated around 150 °C, due to the high load of the quadratic term for inlet air temperature. The process yield increases with this factor due to the difference between the glass transition temperature (Tg) and the particle temperature. At higher inlet air temperature, the temperature of the particle rises rapidly above Tg, and the droplets stick on the internal surface of the device. In contrast, when the difference is minimal, the droplets sticks in the drying chamber easily by the increasing moisture content and resulted in a lower yield too. This trend agreed with the results published by other researchers (Shishir et al., 2014; Tan et al., 2015; Aragüez-Fortes et al., 2019).

The higher yield with higher maltodextrin content was probably due to the reduction in stickiness via increasing the Tg of the feed material before atomizing. Similar observations were reported by other researchers (Bazaria and Kumar, 2016; Tontul and Topuz, 2017; Aragüez-Fortes et al., 2019).

3.3. Moisture content

The values for moisture content of powders ranged from 4.00 to 4.85% wb, which were like the results in other studies (Moreira et al., 2009; Aragüez-Fortes et al., 2019).

Increase in inlet air temperature caused a decrease in moisture content of the powder, probably due to a great temperature gradient between the droplets and the drying medium, causing fast removal of water (Tontul and Topuz, 2017). According to the regression model (Table 2), increasing maltodextrin content led to a decrease in product moisture content because an increase in total solid content, and the mass of water for evaporation was reduced (Tontul and Topuz, 2017).

Table 1. Experimental data for surface response design.

Temperature (°C)	Maltodextrin (% wb)	Yield (% wb)	Moisture (% wb)	Ascorbic acid retention (%)
130	50.0	60.2	4.85	75.1
130	58.4	70.4	4.52	79.8
130	66.7	81.5	4.22	85.5
150	50.0	61.6	4.65	87.4
150	58.4	74.2	4.23	91.2
150	58.4	73.3	4.45	90.5
150	58.4	74.5	4.45	89.8
150	58.4	75.7	4.36	89.9
150	66.7	79.4	4.23	90.1
170	50.0	60.5	4.34	83.3
170	58.4	67.7	4.24	84.7
170	66.7	78.3	4.00	85.8

The effect of the inlet air temperature and maltodextrin content agreed with the results published by several authors (Moreira et al., 2009; Shishir et al., 2014; Cuevas-Glory et al., 2017; Aragüez-Fortes et al., 2019).

3.4. Ascorbic acid retention

Ascorbic acid is a natural antioxidant which is used as a heat sensitive index since it is highly susceptible to thermal degradation during process. The powders have an ascorbic acid retention between 75.1 and 91.2%, which were like to those found for spray drying of immature acerola (Moreira et al., 2010) and for other spray dried fruit juices (Cuevas-Glory et al., 2017; Pino et al. 2018; Aragüez-Fortes et al., 2019). The positive coefficient of the lineal term showed that an increase in air inlet temperature led to higher ascorbic acid retention. However, the negative effect of the second-order term was higher than the lineal term and consequently, there is a curvature in the contour plot, with a maximum value at 150–160°C. This behavior could be explained considering that at lower inlet air temperature, the slow evaporation rate produces microcapsules with higher density membranes and moisture content, consequently causing a loss of vitamin C. Nevertheless, at air inlet temperatures higher than 160°C, the loss of vitamin C increased due to the high temperature during processing (Gharsallaoui et al., 2007). Other studies also reported similar results (Cuevas-Glory et al., 2017; Pino et al., 2018; Aragüez-Fortes et al., 2019). However, this trend is not in agreement with the results of Moreira et al. (2010), but in this study higher inlet air temperatures were used.

The raised maltodextrin content led to higher ascorbic acid retention.

Table 2. Main effects and interactions of the coded regression models

Parameter	Yield	Moisture	Ascorbic acid retention
Intercept	74.01	4.39	90.05
X_T	-2.60***	-0.17***	2.23***
X_M	7.82***	-0.23***	2.60***
X_T^2	-4.12**	0.04	-7.21***
X_M^2	-2.67*	0.02	-0.71
X_TX_M	-3.37**	0.07	-1.97*
Model *F* value	42.86***	14.68***	37.26***
Lack of fit *F* value	4.20	0.30	5.54
R^2	0.973	0.924	0.969
Adjusted R^2	0.950	0.861	0.943
Predicted R^2	0.790	0.764	0.748
Adequate precision	19.808	13.473	20.133

XT, XM: coded inlet air temperature and maltodextrin content, respectively. *$p \le 0.05$, **$p \le 0.01$, ***$p \le 0.001$.

This trend could be explained by the fact that higher maltodextrin content enhances encapsulation efficiency.

Also, increasing maltodextrin concentration rise the total solids and led to a drying time reduction. Several studies reported a decrease of ascorbic acid degradation with increasing maltodextrin addition rate (Moreira et al., 2010; Cuevas-Glory et al., 2017; Pino et al., 2018; Aragüez-Fortes et al., 2019).

3.5. Optimization of the process

Optimum conditions for powder were determined to obtain maximum process yield and ascorbic acid retention, as well as minimum moisture content. The desirability function of the response surface (Fig. 1) showed an optimum inlet air temperature and maltodextrin content at 144 oC and 66.7% wb based on the feed solids, respectively. By applying these conditions, acerola powder with 81% process yield, 4.2% wb moisture content and 91.2% ascorbic acid retention was produced.

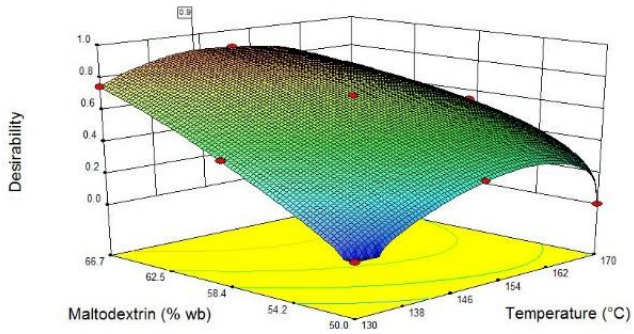

Fig. 1. Response surface plot for optimization of the spray-drying of mature acerola pulp

3.6. Morphology and particle size of the optimized powder

The optimised process produces spherical particles with few cavities and dents. This morphology agrees with previously observed microcapsules of fruit juices with maltodextrins (Cuevas-Glory et al., 2017; Pino et al., 2018; Aragüez-Fortes et al., 2019). The average particle size D43 was 16.3 ± 0.1 μm, lower than 50 μm, commonly found for spray dried fruit juices (Tontul and Topuz, 2017).

3.7. Sensory evaluation of the optimized powder

The acerola powder obtained with the optimum conditions was evaluated as a flavoring to assess the impact of the powder on the pleasure given by an ice cream. The flavour of the ice cream was intense and resembled the fresh acerola fruit. The consumer acceptability was — I like very much — (81% of the total of tests) and — I like moderately — (19%). These results showed that acerola powder exhibited a good acceptance by potential consumers and it is a promising material for food industry.

4. CONCLUSIONS

This study of spray drying of mature acerola pulp revealed that inlet air temperature and maltodextrin content had significant influences on process yield, moisture content and ascorbic acid retention. An increase in the inlet air temperature caused a decrease in process yield and moisture content, with an increase in ascorbic acid retention. Increasing maltodextrin content raised process yield and ascorbic acid retention, with a decrease in moisture content. It was estimated that the optimum air inlet temperature and maltodextrin content to produce spray-dried powder were 144°C and maltodextrin content of 66.7% wb based on the feed solids, respectively. With these conditions, a mature acerola powder with 81% process yield, 4.2% wb moisture content, 91.2% ascorbic acid retention and 16.3 μm of average particle size is produced. The acerola powder exhibited a good acceptance when it was applied to an ice cream.

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