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Optimization of microencapsulation of yellow mombin juice by spray drying using a central composite rotatable design and powder physicochemical properties

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Abstract

Yellow mombin juice was microencapsulated by spray drying. Optimum operating conditions were selected from the outcomes of tests carried out according to a central composite rotatable design, using air inlet temperature (90 to 190 °C), feed flow rate (0.20 to 1.00 L/h) and 15 DE maltodextrin concentration (10 to 30%) as the independent variables, while powder moisture content, water activity, hygroscopicity, total carotenoids retention, and process yield as the responses. As expected, water activity, moisture content and yield of samples were significantly reduced by spray drying. The powder prepared under optimum conditions, whose reconstituted nectar was the most appreciated by panelists in sensory analysis, was partially characterized in terms of physicochemical properties. It exhibited an apparent density of 0.59 g/mL and a solubility of 81.49%. Particles generally occurred in clusters and exhibited spherical shape and smooth surface. The antioxidant activity was shown to be weak to intermediate.

Keywords: *Spondias mombin* L.; atomization; physiochemical properties; spray drying optimization.

Practical Application: Its practical application is based on its use as an ingredient in functional foods.

1 Introduction

A suitable method to microencapsulate food products can be an interesting alternative not only to make them cheaper by reducing transport and storage costs, but also to ensure their storage under room conditions and to satisfy the growing demand for healthy and wholesome products (Krishnaiah et al., 2014; Kalita et al., 2018). Spray drying, also called drying by atomization, is the preferred process for reducing the water content of many chemicals, pharmaceuticals, and foodstuffs (Petersen et al., 2017). Spray drying is also one of the most widely used methods to encapsulate heat sensitive food ingredients such as carotenoids, as the encapsulating agent acts as a coating material (Rocha et al., 2012; Rogers et al., 2012; Corrêa-Filho et al., 2019; O'Sullivan et al., 2019). The coating materials most used to encapsulate the substance of interest and protect it from the effects of drying conditions are biopolymers such as natural gums (e.g., gum Arabic), proteins (e.g., gelatin, whey proteins), and carbohydrates (e.g., maltodextrins, alginates, cellulose derivatives) (Shishir & Chen, 2017).

To best microencapsulate fruit juices, it is important to select, using an appropriate factorial design and on the basis of the experimental data obtained, the optimal conditions capable of ensuring the desired moisture content and the maximum retention of carotenoids in the final product. Several studies are available in the literature on the use of experimental designs to optimize the production of fruit powders using the microencapsulation by atomization (Tonon et al., 2008; Silva et al., 2014; Morais et al., 2020; Souza et al., 2020).

However, research on yellow mombin (*Spondias mombin* L.) is scarce. Not yet adequately exploited commercially, compared to the production of other fruits it presents good prospects for agro-industrial exploitation and could constitute a future source of income for the local population. Yellow mombin, which belongs to the Anacardiaceae family, grows in the tropical regions of the Americas, Africa, and Asia. In Brazil, it is mainly found in the northern and northeastern regions (Sacramento & Souza, 2000). Its tree has great economic potential, and the fruit it produces is widely accepted for its exotic flavor and aroma. The production and processing of its fruit are important economic activities for the regional market (Tiburski et al., 2011).

Since it is a fruit with a high economic and nutritional value, its use as a source of physiologically active and healthy food is of great benefit to the producer and the consumer. As it is well known from mechanistic and clinical data, vitamins and folate, polysaccharides and dietary fiber, lipids, peptides, and natural polyphenols are of great importance for the body's immune system (Watson & Preedy, 2016; Calder et al., 2020; Castro et al., 2020). These bioactive compounds can be found in fruits and vegetables such as the yellow mombin. In addition, considering the implications of the COVID-19 era, the food

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industry claims more recognition of immune-boosting ingredients, and compounds like polyphenolic acids have been suggested as SARS-CoV- 2 protease potential inhibitors (Galanakis et al., 2020).

Based on the above background, the objectives of this work were a) to study the influence of drying conditions, namely inlet air temperature, feed flow rate and maltodextrin concentration, on the process yield, moisture content, hygroscopicity, water activity and total carotenoids retention in the yellow mombin juice powder, b) to sensorially evaluate the best powder, and c) to characterize it in terms of density, solubility, morphology and antioxidant activity.

2 Material and methods

2.1 Materials

Yellow mombin fruits were purchased from the Supply and Logistics Center of Pernambuco (Recife, PE, Brazil). Semi-ripe and ripe fruits were selected, washed in running water, sanitized, and pulped. The pulp was stored in a frozen chamber at -22 °C and thawed in polyethylene bags, according to the quantity required for each test. Maltodextrin MOR-REX® 1914 (Corn Products, Mogi-Guaçu, SP, Brazil) with 15 dextrose equivalent (DE) was used as a carrier agent. The physicochemical and colorimetric composition of the yellow mombin pulp is shown in Table 1.

2.2 Methods

Sample preparation

The pulp was sifted to eliminate particles with diameter greater than that of the atomizer nozzle (1.2 mm) to facilitate its passage. Maltodextrin was added to the pulp under magnetic stirring until complete dissolution. Water (50% v/v) was added before the solution entered the atomizer.

Spray drying

A lab-scale mini atomizer, model MSD 1.0 (Labmaq, Ribeirão Preto, SP, Brazil), was used at a 30-m^3/h air flow and 0.6-bar air pressure. The mixture was fed into the chamber through a peristaltic pump at a feed flow rate ranging from 0.2 to 1.00 L/h and an inlet air temperature ranging from 90 to 190 °C, according to the experimental design.

Experimental design

A central composite rotatable design (Khuri & Cornell, 1996) was used for designing the experiments of yellow mombin pulp spray drying using three independent variables, namely inlet air temperature (x_1), feed flow rate (x_2), and carrier agent concentration (x_3). Five levels were chosen for each variable, including the central point and two axial points. A total of 17 combinations were tested, including three replicates of the central point (Table 2).

It has been assumed that the values of each response variable, y, namely moisture content, water activity, hygroscopicity, total carotenoids retention (TCR) of powders, and process yield, can be correlated to those of the above independent variables (Khuri & Cornell, 1996) by the second-order polynomial function (Equation 1):

$$y = j\left(x_1, x_2, x_3\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \quad (1)$$

where β_0 is the constant regression coefficient, β_1, β_2 and β_3 are the linear regression coefficients, β_{11}, β_{22} and β_{33} are the quadratic coefficients, and β_{12}, β_{13} and β_{23} are the coefficients of interaction effects.

The Statistica 7.0 software (StatSoft, Tulsa, USA) was used to estimate regression coefficients, to perform analysis of variance (ANOVA) and *F*-test for lack of fit and to create three-dimensional graphs.

Physicochemical properties and particle morphology

Powders of yellow mombin juice were analyzed for moisture content, water activity, hygroscopicity and total carotenoids retention. Moreover, after selecting the powder that exhibited

Table 1. Physicochemical and colorimetric composition of *in natura* yellow mombin pulp.

Component	Average value	Method of analysis
Water activity	0.98 ± 0.00	Water activity analyzer
Moisture (%)	81.49 ± 0.27	Moisture analyzer
Soluble solids (° Brix)	9.33 ± 0.57	Refractometer
Titratable acidity (g of citric acid)	3.27 ± 0.11	Association of Official Analytical Chemistry (2006)
pH	2.34 ± 0.02	pH meter
Proteins (%)	1.02 ± 0.13	Association of Official Analytical Chemistry (2002)
Lipids (%)	0.33 ± 0.03	Association of Official Analytical Chemistry (2002)
Carbohydrates (%)	16.41 ± 0.90	Mass difference
Carotenoids (μg/g of β-carotene)	54.80 ± 6.92	Rodriguez-Amaya (1999)
Ashes	0.75 ± 0.05	Association of Official Analytical Chemistry (2002)
Color		McGuire (1992)
L* (luminosity)	73.82 ± 0.48	
a * (green-red component intensity)	-2.73 ± 0.17	
b * (blue-yellow component intensity)	47.17 ± 0.60	

Table 2. Water activity (a_w), moisture content (M), hygroscopicity (H), Process yield (Y) and total carotenoids retention (TCR) of yellow mombin juice powder. x_1 = temperature; x_2 = feed flow rate; x_3 = maltodextrin concentration.

Run	x_1	x_2	x_3	a_w	M	H	Y	TCR
				(-)	(%)	(g/100 g)	(%)	(%)
1	-1 (110)	-1 (0.36)	-1 (14)	0.22	4.42	14.38	21.12	38.96
2	+1 (170)	-1 (0.36)	-1 (14)	0.11	2.38	20.40	19.80	30.89
3	-1 (110)	+1 (0.84)	-1 (14)	0.28	5.40	18.85	21.62	25.68
4	+1 (170)	+1 (0.84)	-1 (14)	0.10	2.43	14.44	19.44	32.49
5	-1 (110)	-1 (0.36)	+1 (26)	0.19	3.90	17.37	16.04	51.32
6	+1 (170)	-1 (0.36)	+1 (26)	0.10	1.88	20.79	13.23	35.98
7	-1 (110)	+1 (0.84)	+1 (26)	0.19	3.96	12.99	14.35	25.34
8	+1 (170)	+1 (0.84)	+1 (26)	0.12	2.13	15.67	14.83	37.61
9	0 (140)	0 (0.60)	0 (20)	0.17	2.93	20.08	20.38	79.73
10	0 (140)	0 (0.60)	0 (20)	0.17	2.97	20.58	20.53	80.33
11	0 (140)	0 (0.60)	0 (20)	0.17	2.98	20.23	20.45	76.70
12	-1.68 (90)	0 (0.60)	0 (20)	0.24	4.36	15.82	21.81	38.88
13	+ 1.68 (190)	0 (0.60)	0 (20)	0.09	2.39	16.84	20.84	60.36
14	0 (140)	-1.68 (0.20)	0 (20)	0.11	2.19	16.76	20.12	41.75
15	0 (140)	+ 1.68 (1.00)	0 (20)	0.12	2.89	20.10	21.12	87.00
16	0 (140)	0 (0.60)	-1.68 (10)	0.11	3.86	15.10	23.60	87.81
17	0 (140)	0 (0.60)	+ 1.68 (30)	0.14	2.53	20.56	18.00	29.56

the optimal combination of responses and sensory analysis outcomes, samples were analyzed for morphology, apparent density, solubility, and antioxidant potential. Analyses were performed in triplicate according to the procedures described below.

Water activity, moisture content and hygroscopicity

A water activity analyzer (Aqualab model 4TE, Decagon Devices, Pullman, WA, USA) was used at room temperature (25 °C) to determine water activity. The moisture content of samples was determined by using a moisture analyzer (model IDSO, Marte Científica, São Paulo, SP, Brazil). Hygroscopicity was determined according to the methodology proposed by Cai & Corke (2000).

Total carotenoids retention (TCR)

The total carotenoid content (TCC) was quantified according to Rodriguez-Amaya (1999). In short, the absorbance was measured at a wavelength of 450 nm. An extinction coefficient of 2500 was used in the mathematical expression described by Gross et al. (1973) to express the results in µg of β-carotene equivalent/g. Total carotenoids retention (TCR) of powders was determined according to the Equation 2:

$$\text{TCR}(\%) = B / A \times 100 \tag{2}$$

where *A* is value of TCC in the pulp before atomization (g dry weight) and *B* that in the powder (g dry weight).

Apparent density and solubility

The apparent density (ρ_b) was measured using a procedure described in previous studies (Barbosa-Cánovas & Juliano, 2005; Caparino et al., 2012). Solubility was determined according to the methodology described by Cano-Chauca et al. (2005).

Scanning electron microscopy

Samples were fixed in metallic containers for specimens (stubs) with a conventional conductive double-sided adhesive tape and then gold metalized for 80 s at a 40-mA current to ensure a covering thickness of 10 nm. Afterwards, samples were examined in a scanning electron microscope (Quanta 200 FEG model, FEI, Eindhoven, The Netherlands) operating at 20 kV.

Sensory analyses of nectars

Before conducting sensory tests, this work was approved by the Research Ethics Committee of the University of Pernambuco, with CEP/UPE and CAAE Registry numbers of 235/11 and 0236.0.097.000-11, respectively. Each panelist signed a Free and Informed Consent Term in which he/she declared to agree to voluntarily participate in the sensory evaluation.

To sensorially evaluate powdered yellow mombin, a nectar was made with fresh pulp and two others with pulp atomized under two different conditions, namely Condition A (feed flow rate of 0.60 L/h, temperature of 140 °C and concentration of carrier agent of 20%) and Condition B (feed flow rate of 0.74 L/h, temperature of 140 °C and concentration of carrier agent of 10%). The nectar obtained from the fresh pulp was prepared by diluting the pulp in the proportion of 1:4 with mineral water, that is up to 250 g/L, while that from the atomized yellow mombin juice by diluting 60 g of powder (equivalent to 500 g of pulp) in 2 L of water. Before conducting sensory tests, in accordance with the provisions of Resolution CNNPA nº 12 and Resolution RDC nº 12, nectars were analyzed microbiologically for Coliforms at 45 ºC and *Salmonella* spp. according to the methods 966.24 and

967.26 of Association of Official Analytical Chemistry (2006), respectively. Sensory tests were performed at room temperature in individual booths. Nectars at 6 ± 2 °C (30 mL) were offered to panelists (37 women and 29 men) in transparent 50-mL cups. The acceptance test was performed using a 9-point structured hedonic scale, ranging from "disliked very much (1)" to "liked very much (9)", through which panelists evaluated the sensory attributes of color, aroma, taste and appearance. The purchase intention was checked employing a structured 5-point scale, ranging from "certainly would not buy (1)" to "certainly would buy (5)" (Wichchukit, & O'Mahony, 2011; Vanhonacker et al., 2013). The multiple comparison preference test was performed using a 7-point structured hedonic scale, ranging from "extremely less preferred than standard (1)" to "extremely more preferred than standard (7)". Samples were served at one time and under red light to mask possible color differences among nectars and presented in randomized complete blocks.

Antioxidant potential

The antioxidant potential, expressed as ability to scavenge the 1,1-diphenyl-2-picryl hydrazine radical ($DPPH^{\cdot}$), was determined according to modifications of the method of Brand-Williams et al. (1995) proposed by Sánchez-Moreno et al. (1998). The scavenging ability was either expressed as half maximal effective concentration (EC50) in g sample/g DPPH as described by Rufino et al. (2010) or as a percentage in relation to the control without antioxidant.

The ability to scavenge the 2.2'-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid ($ABTS^{+\cdot}$) radical cation was determined according to the method described by Re et al. (1999), and the results were expressed as Trolox Equivalent Antioxidant Capacity (TEAC) in mol Trolox equivalent/g.

3 Results and discussion

3.1 Water activity and moisture content of powders

The results listed in Table 2 show that the water activity varied from 0.09 to 0.28, i.e., it was always below the maximum value (0.30) considered microbiologically safe for foods. The range considered optimal for spray dried products is within the limit recommended to ensure microbiological stability (< 0.6) (Favaro-Trindade et al., 2010). For most food systems, in fact, the critical activity of water below which no microorganism can grow commonly varies from 0.6 to 0.7 and that for the growth of pathogenic bacteria is fixed at 0.85-0.86. Since all the values of this parameter obtained for the powders in the present study were considerably lower than these critical threshold values, we can infer that they would be safe in terms of development of pathogenic bacteria (Lascano et al., 2020). Similar values have been reported for red mombin (Morais et al., 2020) and umbu (Silva et al., 2014; Souza et al., 2020) powders obtained by spray drying.

The results of ANOVA applied to the quadratic model of the response surface are listed in Table 3. Not significant variables were omitted, and the other coefficients were used in the final predictive equations.

The Pareto chart revealed that none of the three independent variables, namely the inlet air temperature, feed flow rate, and carrier agent concentration, had a statistically significant effect on the water activity of the yellow mombin juice powder (Figure 1A).

On the other hand, all the independent variables statistically significantly influenced the powder moisture content (Figure 1B), and all regression coefficients were found to be significant ($p < 0.05$). Since the determination coefficient (R^2) for the adjusted model was satisfactory (0.92) and the F-value was greater than the tabulated F-value, the regression model was significant at the considered confidence level and suitable for forecasting purposes (Table 3). Additionally, it was possible to determine the significant regression coefficients for the moisture content, as shown in Equation 3:

$$Moisture(\%) = 2.93 - 0.89x_1 + 0.18x_2 - 0.36x_3 + 0.21x_1^2 - 0.08x_2^2 + 0.14x_3^2 - 0.09x_1x_2 + 0.14x_1x_3 - 0.09x_2x_3 \quad (3)$$

The lack of fit was significant for the moisture model (Table 3). However, when the pure error value is low, i.e., the reproducibility is very good, resulting in a false result of lack of fit, since the F calculated value is high due to the very low value of the denominator, the model has statistical and predictive significance, and there is no lack of fit.

The response surface plots of Figures 2 and 3, which were constructed to visualize the influence of variables on the moisture content of particles, show that such a response was affected by an increase in the air temperature. A similar behavior was reported for spray drying of cagaita extract (Daza et al., 2016) and açai juice (Tonon et al., 2008). Kha et al. (2010) suggested that an increase in air temperature results

Table 3. Results of ANOVA for the response surface quadratic model.

Source	Df	a_w	Moisture (%)	Hygroscopicity (g/100g)	Yield (%)	TCR (%)
Regression	5	0.042895^{ns}	14.41298*	69.4707*	935.138	4.386.063
Residual	7	0.006329	127.457	429.705	442.052	3.984.762
Lack of fit	5	0.001266^{ns}	1.27317*	42.8388*	44.1939*	3977.189*
Pure Error	2	0.00000^{ns}	0.00140^{ns}	0.1317^{ns}	0.0113^{ns}	7.573^{ns}
Cor	16	0.049224	1.568.755	1.124.412	1.377.190	8.370.825
R-Squared		0.87	0.92	0.61	0.67	0.52

Df = Degree of freedom; TCR = total carotenoids retention; a_w = water activity. ns: Not significant ($p > 0.05$). *Statistically significant at $p < 0.05$.

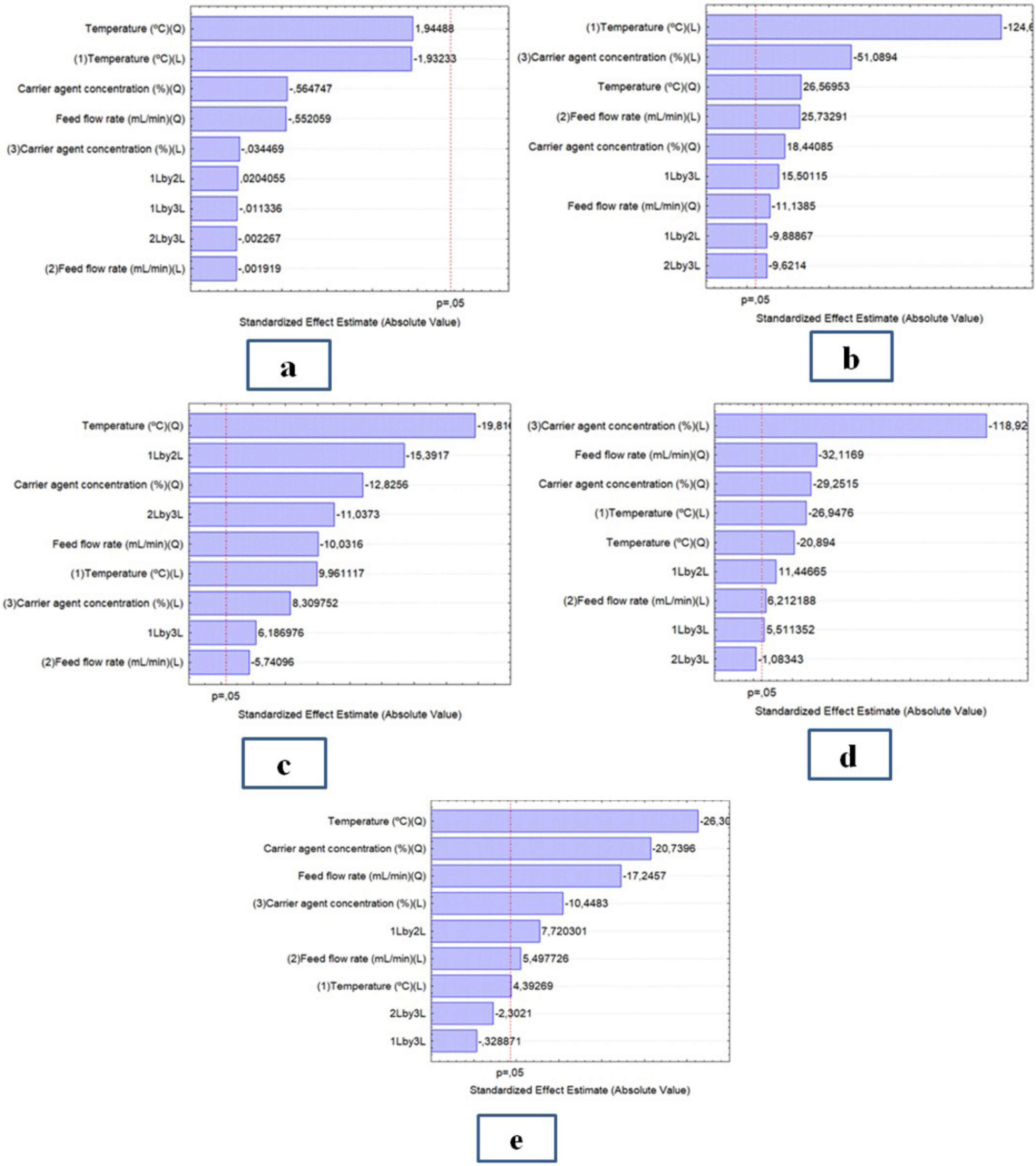

Figure 1. Pareto charts of dependent variables: (a) water activity, (b) moisture, (c) hygroscopicity, (d) process yield, and (e) total carotenoids retention.

in a greater water loss in powders due to a higher rate of heat transfer to the particles, thus leading to a greater driving force for water evaporation.

The concentration of the carrier agent also had a negative effect on this response, similar to what was observed for spray drying of tomato paste and other plant food products (Goula & Adamopoulos, 2005; Grabowski et al., 2006; Quek et al., 2007; Gong et al., 2008; Jittanit et al., 2010). This result may have been due to the ability of maltodextrin to reduce the high hygroscopicity of powdered fruit sugars and therefore to hinder

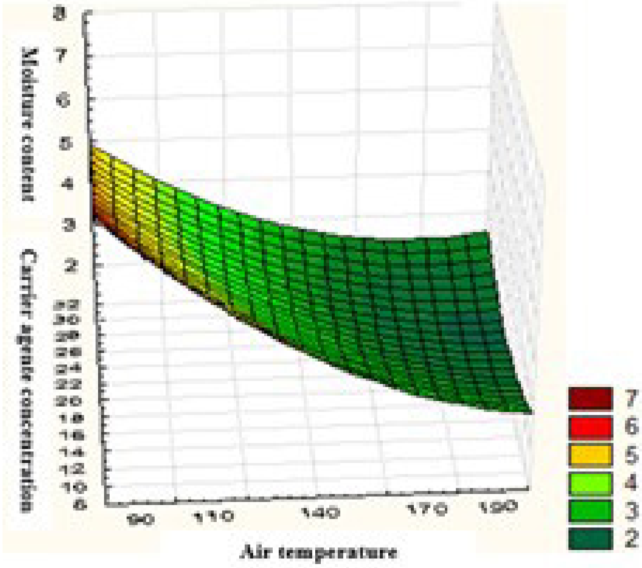

Figure 2. Response surface of moisture content of atomized yellow mombin particles as a function of carrier agent concentration (10 to 30%) and air temperature.

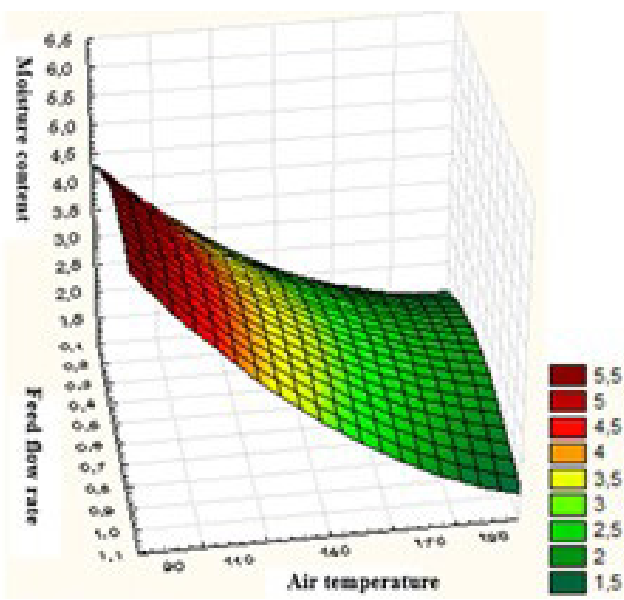

Figure 3. Response surface of moisture content of atomized yellow mombin particles as a function of feed flow rate (0.20 to 1.00 L/h) and air temperature.

moisture absorption from the surrounding air (Shrestha et al., 2007). Morais et al. (2020), in their effort to optimize the conditions of red mombin juice spray drying, have recently observed that both responses were negatively influenced by temperature and positively by flow rate, while maltodextrin concentration exerted a negative effect. Contrariwise, Souza et al. (2020) did not observe any significant influence of temperature, feed flow rate and 10 DE maltodextrin concentration when producing umbu powder.

3.2 Hygroscopicity

Although the regression coefficients of the model for hygroscopicity were significant (Figure 1C), the coefficient of determination (R^2) was too low (0.616); therefore, this model can only be used to get only an idea of results, but not for predictive purposes. The hygroscopicity of yellow mombin juice powder ranged from 12.99 to 20.79 g/100 g (Table 2). These values are smaller than those reported for passion fruit juice powder (17.4-35.4 g/100 g) produced by atomization using lactose and maltodextrin as carrier agents (Ruiz-Cabrera et al., 2009) and close to those reported for red mombin microencapsulated by spray drying (16.16-20.86 g/100 g) using 10 DE maltodextrin (Morais et al., 2020). Daza et al. (2016) observed, by spray drying cagaita extract, that an increase in process temperature resulted in a powder with greater hygroscopicity, since the higher the temperature, the smaller the size of particles and the larger their exposed area. On the other hand, Souza et al. (2020) observed that umbu powder hygroscopicity was mainly affected by the concentration of 10 DE maltodextrin. In particular, due to the low hygroscopicity of this coating agent, the higher its concentration, the lower this property. Finally, Silva et al. (2014) did not observe any statistically significant effect of the studied operational conditions such as inlet air temperature, feed flow rate and 15 DE maltodextrin concentration on umbu powder hygroscopicity.

3.3 Process yield

The interaction between feed flow rate and maltodextrin concentration was the only factor that statistically significantly influenced the process yield (Figure 1D). However, due to the too low value of R^2 (0.673), the model was not able to describe the variations observed for this response. The average yield for yellow mombin juice powder was approximately 19.5%, a value close to those found by Silva et al. (2014) for umbu powder (7.34-20.49%), while a very large range (5.15-48.13%) was reported by Krishnaiah et al. (2012) for spraying drying of *Morinda citrifolia* L. extracts using two different carrier agents (κ-carrageenan and maltodextrin) at different temperatures (90-140 °C). The low yield obtained in the present study can be explained by an insufficiently large drying chamber (Truong et al., 2005) as well as the presence of sugars and acids with low molar masses and low glass transition temperatures, which adhered to the dryer wall during the process, thus increasing viscosity, causing powder sintering (Gharsallaoui et al., 2007) and consequently affecting the spray drying performance (Goula & Adamopoulos, 2005; Wang & Langrish, 2009).

3.4 Total Carotenoids Retention (TCR)

The regression coefficients of the model used to describe the effect of the three independent variables on the retention of total carotenoids were statistically significant (Figure 1E), with the exception of those referring to the interactions between inlet air temperature and maltodextrin concentration and between feed flow rate and maltodextrin concentration. However, as was the case for hygroscopicity and process yield, the model had so low R^2 value (0.616) that it cannot be used for predictive purposes. The values of TCR in yellow mombin juice powders, ranging from 25.34 to 87.81% (Table 2), were well above those observed for red mombin powders (14.90-33.43 g per 100 g) obtained under similar spray drying conditions (Morais et al., 2020). It is well known that the degradation of carotenoids is kinetically favored by the presence of oxygen and by an increase in temperature. However, in this study, the highest total carotenoid retention in yellow mombin juice powders (87.81%) was achieved operating at intermediate temperature (140 °C) and feed flowrate (0.60 L/h) as well as the lowest concentration of maltodextrin (10%) (run 16). It is likely that a temperature reduction led to powders with greater tendency to agglomerate due to their higher moisture content (Quek et al., 2007) and that the agglomerates reduced the powder exposure to oxygen, thus protecting carotenoids from oxidation. However, at too low temperature (110 °C) or higher coating agent levels, moisture or maltodextrin may have reduced the space available for carotenoids retention.

3.5 Selection of the best drying condition

A joined analysis of results pointed out that all samples had low moisture contents and water activity values consistent with good resistance to microbial spoilage. The best atomization conditions were chosen considering simultaneously all the observations made, with the aim of obtaining powders with the greatest retention of total carotenoids, the best appearance and quality, and the maximum yield.

3.6 Sensory evaluation of nectars

The absence of *Salmonella* sp. and coliforms (results not shown) confirm that sanitary and hygienic procedures were correctly followed in the development of atomized juice and that there was no contact with these microorganisms after processing. The results of the sensory analysis carried out according to the affective test of acceptance for the different formulations are listed in Table 4. Comparing the averages of each attribute, namely color, aroma, flavor, and appearance, it was found that there were no significant differences ($p > 0.05$) between samples. Nonetheless in general, the scores awarded to all attributes of the nectar formulated from the powder produced under condition B were higher than those under condition A, varying in the hedonic scale from “indifferent” to “liked slightly”. The results also show that neither of the two formulations was more accepted by the panelists compared to the attributes evaluated individually.

The purchase intention test highlighted percentages of panelists who “certainly and probably […] would buy” the product of 37.0 and 58.0% for nectars reconstituted from yellow mombin powders produced under conditions A and B, respectively, while the percentages of those who “Certainly and probably […] would not buy” were 20.0 and 5.1%, respectively. It was also observed that no panelist opted for the “Certainly would not buy” option, as 8.2 and 15.0% were undecided and opted for the “Maybe I would buy/Maybe I wouldn’t buy” one.

Table 4. Average scores followed by standard deviation awarded by the affective test of acceptance to the attributes of nectars reconstituted from yellow mombin juice powder under two different conditions.

Formulation	Color	Aroma	Flavor	Appearance
Condition A	$5.5^a \pm 1.3$	$4.8^a \pm 1.4$	$4.9^a \pm 1.4$	$5.4^a \pm 1.3$
Condition B	$5.9^a \pm 1.0$	$4.7^a \pm 1.2$	$5.2^a \pm 1.2$	$5.5^a \pm 1.5$

Table 5. Average scores followed by standard deviation awarded by the multiple comparison preference test to aroma and flavor of nectars reconstituted from yellow mombin juice powder under two different conditions compared to the *in natura* juice.

Formulation	Aroma	Flavor
Condition A	$2.4^a \pm 1.2$	$3.0^a \pm 2.0$
Condition B	$2.7^a \pm 1.5$	$3.3^a \pm 1.9$

Means followed by the same letter in the column do not differ significantly at the 5% probability level by the Tukey test. Condition A: feed flow rate of 0.60 L/h, air temperature of 140° C and concentration of carrier agent of 20%. Condition B: feed flow rate of 0.74 L/h, air temperature of 140 °C and concentration of carrier agent of 10%.

The results of the multiple comparison preference test (Table 5) show that, although there was no statistically significant difference between the scores attributed to the aroma and flavor of nectars reconstituted from powders prepared under conditions A and B, the latter received as a whole better scores for both attributes. This result suggests that condition B provided a powder with characteristics closer to the *in natura* product.

3.7 Physical characterization of the best powder

The apparent density value (0.59 g/mL) indicates that the yellow mombin juice powder was relatively heavy, which allowed it to settle in the interstices among particles, occupying a small volume. Higher values have been reported for atomized red mombin (Morais et al., 2020), while atomized umbu showed divergent results likely due to different atomization conditions (Silva et al., 2014; Souza et al., 2020). Moreover, on average, the atomized yellow mombin powder had a solubility (81.49%) lower than that reported for umbu powder (80.20-90.95%) (Silva et al., 2014; Souza et al., 2020) but comparable to that of red mombin powder (79.70%) (Morais et al., 2020). The scanning electron micrographs illustrated in Figure 4 point out that microparticles had spherical shape and smooth surface without breaks. Some particles showed winkled surface, a characteristic feature of spray-dried powders that can be associated to the fast loss of water during the initial stages of drying and the high temperature used in the drying chamber. Similar results were obtained for atomized umbu (Silva et al., 2014; Souza et al., 2020) and atomized red mombin (Morais et al., 2020).

3.8 Antioxidant activity of the best powder

The antioxidant capacity of the yellow mombin juice powder expressed as EC50 was 159.39 ± 3.81 g sample/g DPPH, while capacity to scavenge the $ABTS^{\bullet+}$ radical cation was about 19.63 ± 0.94 µmol TEAC/g. According to Kim et al. (2003), the antioxidant capacity can be influenced by factors such as type

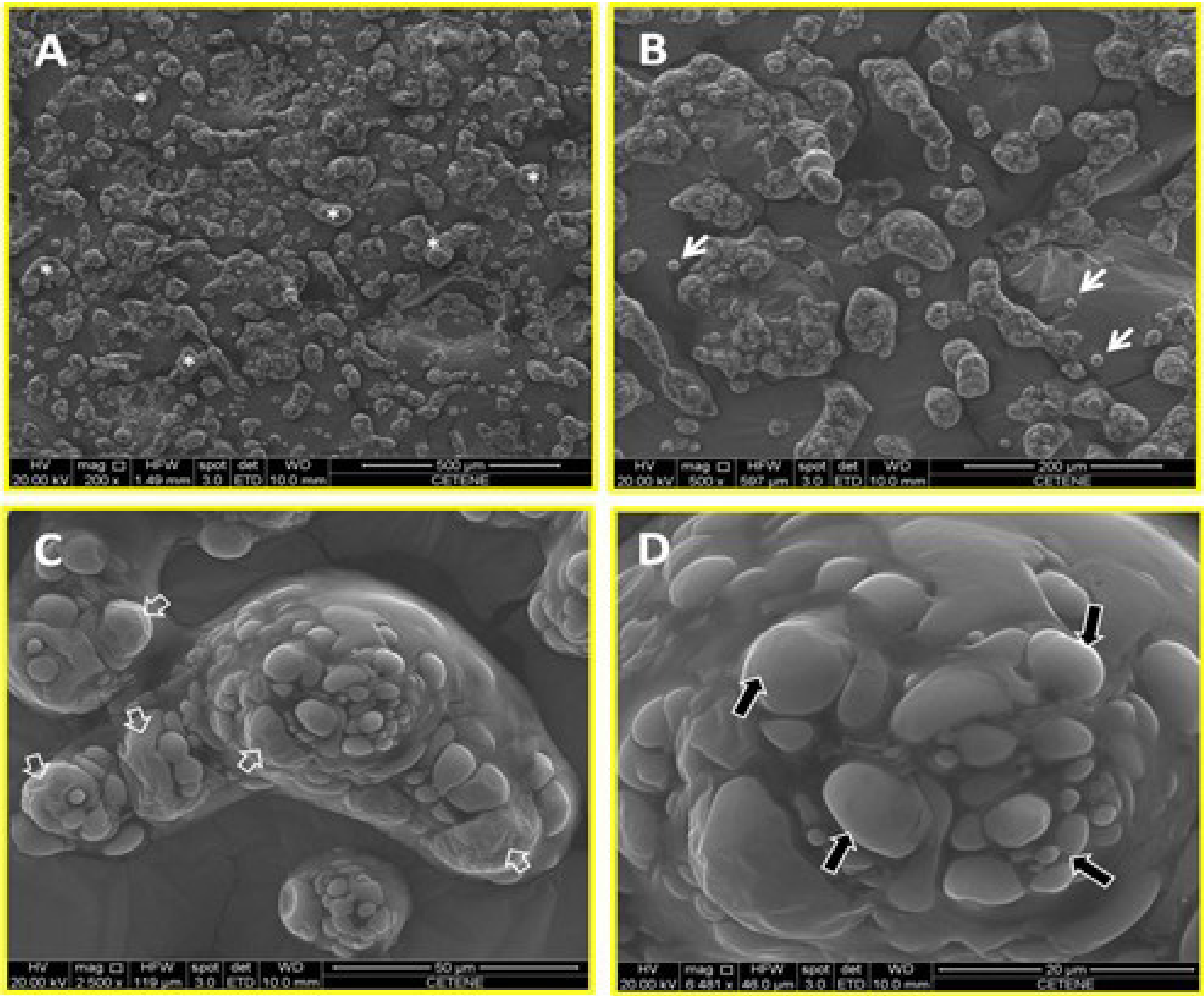

Figure 4. (A-D): Electromicrographs of atomized yellow mombin particles. A – Overview of the distribution of particles in the form of agglomerates with different size (asterisks); B – Isolated particles (short arrows); C and D – Details of the agglomerate formed by particles of different size that had a rough surface (open arrow) and a smooth surface (closed arrow).

of carrier agent, fruit maturity, species, cultivation practices, geographical origin, growth stage, crop conditions, storage process and preservation method, which could explain the difference in the antioxidant potential of yellow mombin in relation to other atomized fruit juices. For instance, Badmus et al. (2016) and Naji-Tabasi et al. (2021) reported values of $DPPH^{\cdot}$ inhibition ranging from 26.81 to 28.74% for *Arenga pinnata* juice powder and from 69.34 to 75.46% for barberry juice powder, respectively. On the other hand, Araujo et al. (2021) detected for sapota juice powder antioxidant activities by the $ABTS^{+\cdot}$ method in the range 469.59-834.11 µM of TEAC/100 g and by the $DPPH^{\cdot}$ one in the range 47.67-113.18 µM of TEAC/100 g.

4 Conclusion

Response Surface Methodology applied to second-order models and sensory tests allowed selecting an inlet air temperature of 140 °C, an inlet feed flow rate of 0.74 L/h, and a 15-DE maltodextrin concentration of 10% as the best conditions to spray dry yellow mombin fruit juice. Scanning electron microscopy examination revealed that most of powder particles had continuous wall and smooth external surface with generally spherical shape and very little fragmentation. The yellow mombin juice powder exhibited good solubility and retention of total carotenoids as well as a weak/intermediate antioxidant activity. In addition, the low moisture content and water activity of powders are consistent with excellent stability against microbial spoilage during storage at room temperature and are expected to reduce transportation costs compared to the conventional *in natura* fruit or juice.

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