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Osmotic Dehydration Process Study With Complementary Banana Peel Drying

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Abstract

The present study aims to perform combined osmoconvective and convective drying processes on banana peel and evaluate the influence of these processes on their physical and physical-chemical properties. A factorial planning of 2^2 + 3 central points was carried out to evaluate the effect of the input variables: sucrose concentration varying between 40 and 60 °Brix and temperature between 40 and 60 °C, on the response variables: loss of water and mass and gain of solids in the banana peels. The drying kinetics was performed at 60 °C and empirical mathematical models were adjusted to the experimental data. The fresh peels, osmotically dehydrated, after drying process (in the optimized condition) and during 30 days of storage were characterized as for the parameters: pH, total titratable acidity (TTA), total soluble solids (TSS), TSS / TTA ratio, water content and total solids, ash, ascorbic acid, reducing sugars, color (L *, a * and b *) and water activity (Aw). The banana peels used in the experiments had a high water content and reasonable amounts of carbohydrates and ashes. The condition that showed the greatest reduction in water content and greatest gains in solids was using the temperature of 60 ° C and 60 ° Brix, being considered the optimized. The osmoconvective dehydration process resulted in a greater incorporation of total soluble solids and higher percentages of total solids in the shells. Page's mathematical model was the one that best fitted the experimental data; the effective diffusivity of the process was 2.2 x 10^{-8} $m^2.s^{-1}$. And the physical and physical-chemical parameters analyzed during the storage had small changes during the period of 30 days of storage.

Keywords: experimental planning, *Musa* ssp, waste, storage

1. Introduction

The banana (*Musa* ssp.) is one of the most popular tropical and subtropical fruits and consumed worldwide due to its high nutritional value (Chen *et al*., 2019). The high demand for bananas in the fruit market generates large amounts of waste, in which the peel represents 35% of the total weight of the fruit and is generally disposed of inappropriately. This material is rich in dietary fibers and phenolic compounds, which makes them promising for a variety of applications in the food and pharmaceutical industries (Vu *et al.,* 2019).

Sulistyawati *et al.* (2018) states that the application of osmotic dehydration in agro-industrial waste is an excellent alternative to add greater value to this waste. Thus, the processing of banana peels, in addition to enabling the production of a food with high added value, provides the minimization of an environmental problem that is the disposal of this waste (Panesar *et al*., 2016).

According to Papazoglou and Katsanidis (2019), osmotic dehydration is a process in which water is removed and solids in food are incorporated, providing an increase in the shelf life of products and improving functional and sensory attributes such as flavor, aroma and texture. The mass transfer process occurs due to the insertion of the product in a hypertonic solution and the osmotic pressure gradient between the product and the solution is the necessary driving force for the removal of water, also influenced by the permeability of the membrane (Bozkir *et al*., 2019; Rahaman *et al.,* 2019).

The use of drying processes reduce the water content to safe levels of storage, since it involves heat and mass transfers, influencing the biological activities and the chemical and physical structure of the product, depending on the conditions and drying methods applied (Almeida *et al*., 2020).

Given the above, researches regarding the use of residues brought about in the banana processing, especially of its peels, are fundamental both from the environmental point of view and for the development and rise of their value, making them safe food products. The present study aims to perform combined osmoconvective and convective drying processes on banana peel and to evaluate the influence of these processes on their physical and physical-chemical properties.

2. Methodology

Prata banana peels came from fruits selected for their apparent quality: yellow color and without black dots, obtained in the city of Campina Grande, Paraíba. The peels were subjected to an initial wash, then they were immersed in a 50 ppm sodium hypochlorite solution for 5 minutes and finally they were washed again to remove the excess of this solution. After the sanitization process, the peels were cut manually with a dimension of 0.5 x 3.0 cm and immediately submitted to the bleaching pretreatment (immersion in boiling water for 4 minutes, followed by cooling in water at a temperature of ± 10 ° C to avoid prolonged heat action).

Factorial experimental design for osmotic dehydration

An experimental planning 2^2 was carried out with 3 replications at the central point, making it 7 assays to evaluate the influence and experimental behavior of the independent variables (input variables), sucrose concentration and temperature, on the response variables (dependent), water loss (WL), loss of mass (LM) and solids gain (SG) in osmotic dehydration.

The planning matrix, with its respective independent variables and its real and coded levels, are shown in Table 1. The effect of the independent variables on the dependent variables was evaluated by means of statistical analysis, using the computer program Statistica® version

Table 1. Planning matrix for osmoconvective dehydration of banana peels, with their respective independent variables and their real and coded levels

Assay	Independent variables	
	Sacarose concentration (°Brix)	Temperature (°C)
1	-1 (40)	-1 (40)
2	+1 (60)	-1 (40)
3	-1 (40)	+ (60)
4	+1 (60)	+ (60)
5	0 (50)	0 (50)
6	0 (50)	0 (50)
7	0 (50)	0 (50)

Osmotic Dehydration (OD)

The sucrose dehydrating solutions of concentration 40, 50 and 60 °Brix were prepared using commercial sucrose and distilled water. The entire dehydration process took place in a greenhouse with air circulation. The sucrose solution was kept in a water bath until it reached the process temperature, only then it was added to the container containing the samples until the slices were completely immersed.

The mass and water content of the banana peels were determined periodically with 15 minutes span, until the end of osmotic dehydration, with 240 minutes (4h), time verified when the samples reached osmotic balance, with no further mass variation. For each planning experiment, the loss of mass and water content were calculated, according to the methodology described in Brazil (2008).

Mass loss (ML), water loss (WL) and solids gain (SG), were calculated using Equations 1, 2 and 3, respectively.

$$ML(\%) = \left(\frac{M_0 - M_t}{M_t}\right)x100 \tag{1}$$

$$WL(\%) = \left(\frac{M_{w0} - M_{wt}}{M_t}\right)x100 \tag{2}$$

$$SG = WL(\%) - ML(\%) \tag{3}$$

where: M_0 – initial product mass (g); M_t – product mass at time t (g); Mw_0 - water content in the product (g); e Mw_t – water content in the product at time t (g).

Drying kinetics

The banana peels in the best condition of the factorial design of osmotic dehydration were placed on stainless steel screens, and spread evenly, forming a thin layer. To start the experiment, the trays were placed in a dryer with air circulation with an air speed of 1.0 m/s, for the drying kinetics at 60 °C, at the beginning and at the end of the drying the dried masses were determined and the water contents were calculated according to Brazil (2008). Through the experimental data, it was possible to calculate the values of the water content ratio (Equation 4).

$$RX = \frac{X_{db} - X_e}{X_{db\,(initial)} - X_e} \tag{4}$$

where: RX is the moisture ratio (dimensionless); X_e is the equilibrium water content on a dry basis; X_{db} is the water content on a dry basis; $X_{db(initial)}$ is the initial water content on a dry basis.

With the calculation of the water content ratio, the drying kinetics curve was plotted, represented by the water content ratio as a function of the drying time in minutes, applying the mathematical models (Table 2) by Page, Henderson and Pabis and Midilli to adjust the experimental data.

Table 2. Mathematical models used to describe the drying process

Model	Equation	
Page	RX= exp.(-k. t^n)	(5)
Handerson & Pabis	RX= a.exp(-K.t)	(6)
Midilli	RX=a.exp-(kt^n)+bt	(7)

Note: RX: Moisture ratio (dimensionless); k: drying constant; “A”, “n” and “b”: parameters of the models; t: drying time.

To analyze the adjustments of the mathematical models to the experimental data, the computer program STATISTICA, version 7, was used, using the non-linear regression analysis, by the Quasi-Newton method. The models were selected taking as a parameter the magnitude of the determination coefficient (R^2) and the mean square deviation (MSD) (Equation 8).

$$MSD = \sqrt{\sum_{i=1}^{n} \frac{(RX_{exp} - RX_{pred})^2}{N}} \tag{8}$$

where: RX_{exp} is the water content ratio obtained experimentally; RX_{pred} is the water content ratio predicted by the mathematical model; N is the number of observations along the drying kinetics.

The effective diffusion coefficient was determined by adjusting the mathematical model of liquid diffusion (Fick's Law) with an approximation of three terms (Equation 9) to the experimental data on the drying kinetics of banana peels, considering the uniform and the absence of thermal resistance. This model is the analytical solution for the second Fick's Law, considering the geometric shape of the banana peels as approximated to a flat plate.

$$RX = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left[-(2n+1)^2 \pi^2 D \frac{t}{4L^2} \right] \tag{9}$$

where: D is the effective diffusion coefficient ($m^2.s^{-1}$); n is the number of terms in the equation; L is the size of the peel; t is the time (s).

Physical and physical-chemical characterization of banana peel

The banana peels *in natura*, osmotically dehydrated, dried (in the optimized condition) and with 30 days of storage were characterized according to the following parameters: total titratable acidity (TTA), total soluble solids (TSS), TSS / TTA ratio, water content, total solids and ash according to the methodology described by BRASIL (2008). The pH was determined by the potentiometric method. Ascorbic acid (vitamin C) was determined by the methodology described by BENASSI and ANTUNES (1998), and the reducing sugars were determined by the methodology described by Miller (1959). The water activity was determined directly on Decagon Devices' Aqualab 3TE equipment at 25 °C. The color parameters were determined using the Mini Scan Hunter Lab XE Plus spectrophotometer (Reston, VA, USA), in the Cielab color system which allowed obtaining the parameters: L* (luminosity); a*, transition from green (-a*) to red (+ a*); and b*, transition from blue (-b*) to yellow (+ b*).

Statistical analyzes

Statistical analyzes were performed for the experimental data in triplicate and the results were submitted to a single factor analysis of variance (ANOVA) of 5% probability and the significant qualitative responses were submitted to the Tukey test considering the same level of significance, 5%. For the development of statistical analysis, ASSISTAT software version 7.0 was used.

3. Results and Discussions

Table 3 shows the results of the physical-chemical characterization of banana peel *in natura*.

Table 3. Banana peel characterization *in natura*

Parameter	Mean ± Standard Deviation
pH	5.53 ± 0.058
Total soluble solids (Brix)	5.75 ± 0.050
SST/ATT ratio	34.22 ± 1.818
Total titratable acidity (% malic acid)	0.168 ± 0.008
Ascorbic acid (mg/100g of sample)	1.415 ± 0.004
Water content (%w.b.^{1}.)	84.56 ± 0.121
Ashes (%)	1.71 ± 0.121
Total solids (%)	15.44 ± 0.017
Reducing sugars (g/100g)	4.23 ± 0.014
Water activity (wA)	0.966 ± 0.001
L*	56.09 ± 0.038
a*	7.44 ± 0.029
b*	40.45 ± 0.050

Note: ^{1}wet base.

The pH was non-acidic, with an average value of 5.53. The same was obtained by Castilho *et al.* (2014) for prata *in natura* banana peels in the development of flour with residues of *prata* and *maçã* bananas. Viana *et al.* (2017) obtained a slightly lower result in relation to this parameter (5.00) in the banana of the Grande Nain variety. The total soluble solids (° Brix) value was 5.75 °Brix, which was considerably low comparing to the 18 °Brix value for banana pulp found by Pádua *et al.* (2017).

The determination of total titratable acidity (TTA) quantifies the content of organic acids present in foods, with malic acid being the major contributor to the variation in acidity in banana pulps and peels. The average value found for TTA in fresh peel was lower when compared to those obtained by Leite *et al.* (2010), which ranged from 0.39 to 0.43%, for the banana pulp of the pacovan variety in different establishments in Mossoró (Rio Grande do Norte). Due to the low content of soluble solids present in the peel, the TSS / TTA ratio, which represents the content of sweetness and ripeness of the fruit, showed lower values compared to those obtained in the fruit pulp, studied by the same author, which varied 57.55 to 64.37.

The concentrations of ascorbic acid (mg.100g^{-1}) vary according to the genotype studied. According to TACO (2011), banana peels showed low levels of vitamin compared to pulps of the *prata* (21.6), *figo* (17.5) and *terra* (15.7) variaty, and considerable ascorbic acid content compared to the present in the *nanica* banana pulp, 5.9.

The samples *in natura* had a high water content, 84.56%, characterizing the raw material as a perishable product. Neris *et al.* (2018), when determining the water content in prata banana peel at the ripe stage of ripeness, obtained similar results of 81.53%. These authors found ash contents between 1.52 and 1.80% in two sampling units of banana peels, corroborating with the data obtained in this research, which was 1.71%.

The determination of reducing sugars showed a value above that obtained by Castilho *et al.* (2014) which was 2.94 (g/100g) for the banana peel *in natura* of the *prata* variety. This fact can probably be attributed to the stage of ripening of the fruit. Carvalho *et al.* (2011) worked with the Thap Maeo variety of the apple subgroup at different stages of maturation and found values of reducing sugars ranging from 0.71 to 6.01g / 100g.

The water activity value (wA) found, 0.966, is below that obtained in the peel of the mandacaru fruit by Silva *et al.* (2019) which was 0.990.

The parameters luminosity (L*), red (a*) and yellow intensity (b*) determined for the peels *in natura* were 56.09, 7.44 and 40.45, which physically defines the characteristics of the fruit for the stage maturation chosen, ranging from yellow-green to yellow. Analyzing the color parameter (L*) in *prata-anã* banana peels, Astricini *et al*. (2015) found values of 59.34. Differences related to fruit color, can be attributed to the stage of ripeness and the variety used by these authors.

Table 4 shows the experimental values of the dependent variables, determined by means of a $2^2 + 3$ factorial design.

Table 4. Factorial design of osmotic dehydration as a function of sucrose concentration and temperature

Assays	WL (%)	ML (%)	SG (%)
1	31.26	28.79	2.46
2	50.63	44.00	6.63
3	42.15	36.82	5.33
4	56.91	50.74	6.17
5	48.55	42.94	5.60
6	49.36	43.52	5.84
7	48.96	43.25	5.71

Note: WL: Water loss; ML: Mass loss; GS: Solids gain.

Under the conditions used for sucrose concentration and temperature, it appears that the values of water loss (WL) and mass loss (ML) varied from 31.26 to 56.91%, and from 28.79 to 50.74%, respectively. According to the tabulated data, it is possible to verify that these values tend to increase when the highest values are used for the combination of concentration and temperature. Thus, assay 4, was the experiment that had the greatest variations in terms of response variables, WL and ML, while assay 1 was the one with the lowest values. The same behavior for water loss was verified by Porto *et al.* (2014), in the optimization of osmotic dehydration of seedless *Crimson* grapes.

The solids gain showed values between 2.46 to 6.63% and all assays, except for number 1, expressed values above 5%, with assays 2 and 4 being the ones that achieved the highest results, with 6.63 and 6.17%, respectively. Examining factorial design, it is observed that the concentration of sucrose is the variable that has the most influence in increasing this parameter. Likewise, Castro *et al.* (2018), during the study of the development and sensory evaluation of osmotically dehydrated raisin guava, observed that the values of solids gains increased with the elevation of the temperature and mainly with the concentration of sucrose.

Table 5 shows the analysis of variance (ANOVA) applied to the regression of the data of the osmotic dehydration response variables: WL, ML and SG to a linear model and their respective determination coefficients R^2.

Table 5. Analysis of variance (ANOVA) of the models adjusted for the response variables

Variation source	Fcal	Ftab	Fcal/Ftab	R^2
		Water loss (WL)		
Regression	15.40	9.28	1.66	93.90
Lack of adjustment	145.00	18.51	7.83	
		Mass loss (ML)		
Regression	15.56	9.28	1.68	93.96
Lack of adjustment	202.00	18.51	10.91	
		Solids gain (SG)		
Regression	17.97	9.28	1.94	94.73
Lack of adjustment	38.00	18.51	2.05	

Nota: cal: calculated; tab: tabulated.

The significance of the regression and the lack of adjustment when at 95% level of confidence can be observed by the F test, a fact consistent with the coefficient of determination (R^2), which in all showed values above 90%, adjusting well to the mathematical model of linear regression. It appears that, for the regression all the independent variables analyzed, the value of Fc (calculated F) was greater than the value of Ft (tabulated F), therefore, the linear model was statistically significant. The regression model was statistically predictive for all response variables, presenting an Fc/Ft ratio < 4. The lack of adjustment was significant for all independent variables and only the variable solids gain was statistically predictive.

Figure 1 shows the Pareto diagrams generated from the factorial design, which visually express the interaction of the dependent variables on the independent ones, according to their significance and regression, during osmotic dehydration. The magnitude of the effects is represented by horizontally arranged bars and their statistical significance, at the 95% confidence level, by the dashed line perpendicular to the bars ($p = 0.05$).

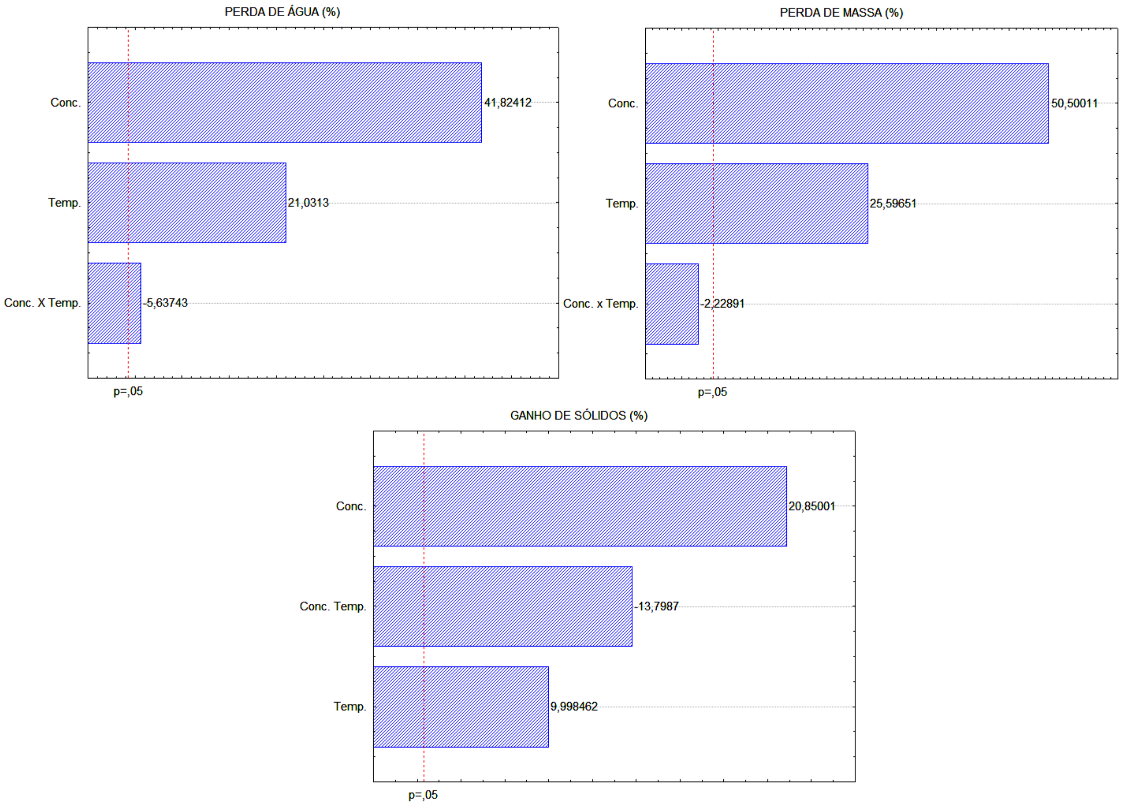


Figure 1. Pareto diagrams for water loss, mass loss and solids gain.

The Pareto diagrams show the loss of mass was the only parameter observed that was not influenced by the interaction between the two independent variables. The solution concentration and temperature were the factors that most influenced statistically the dehydration of banana peels, with positive effects at 95% confidence. Silva *et al.* (2017) when performing osmotic dehydration of pequi pulp, found that the concentration of the sucrose solution was the variable that most influenced the loss of mass of the product.

It appears that the increase in the parameters water loss (WL), mass loss (ML) and solids gain (SG), showed the same behavior, being significantly influenced by the increase in the values of the input variables, sucrose concentration and temperature, a significant factor above 95% confidence, with the concentration of the dehydrating solution the factor that most influenced the increase in the values of these observed parameters. Silva et al. (2015a) also observed that sucrose concentration and temperature were the most effective factors in water loss during osmotic dehydration of the cagaita fruit (*Eugenia dysenterica*).

In the Pareto diagram for solids gain, it is observed that the regression of the factors was significant at 95% confidence, with the concentration of sucrose being the parameter of greatest influence on the increase of this variable during osmotic dehydration, followed by the interaction between variables and temperature. The evaluated data corroborate the study carried out by Castro *et al.* (2018), who also observed that sucrose concentration was the variable with the greatest influence on the incorporation of solids in fruits.

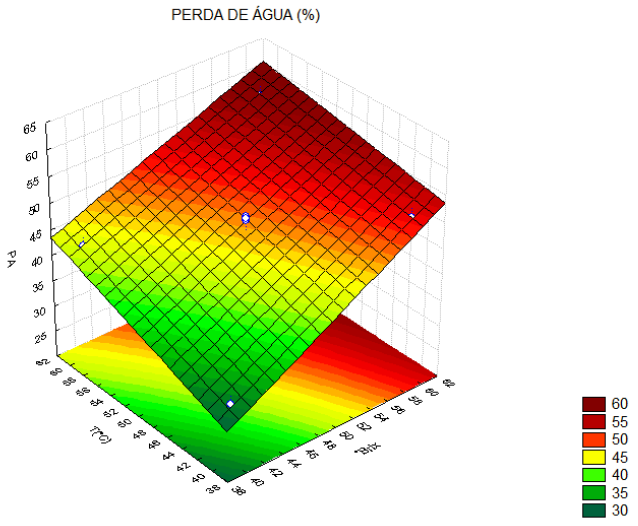
Table 6 shows the equations of the linear models for the response variables, obtained during osmotic dehydration for the banana peel slices, under the different conditions of sucrose (X) and temperature (Y). From these coefficients, the graphics of the response surfaces were generated and analyzed.

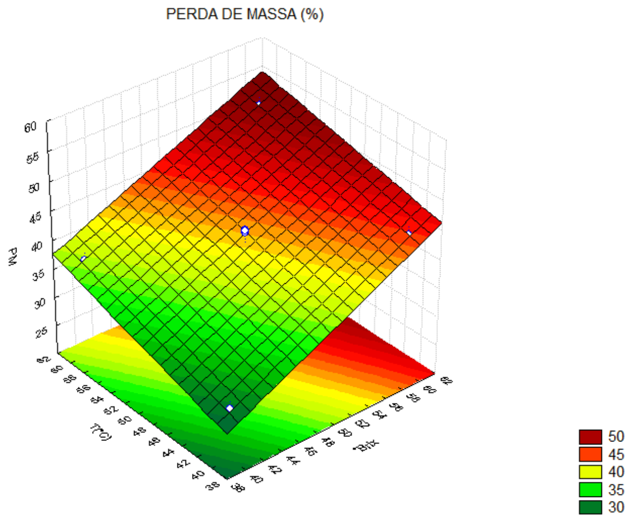
Table 6. Mathematical models of linear regression for response variables

Variables	Estimated model
WL	Z(X,Y) = 1.4295X + 1.0055Y – 0.0115XY – 46.1061
ML	Z(X,Y) = 0.8895X + 0.5305Y – 0.0032XY – 21.5004
SG	Z(X,Y) = 0.5415X + 0.4765Y – 0.0083XY – 24.6961

Note: X: sucrose concentration (°Brix); Y: temperature (°C).

Figure 2 shows the response surfaces obtained for the variables of water loss, mass and solids gain for the osmotic dehydration of banana peel slices that presented statistically significant models (Fc ≥ Ftab).





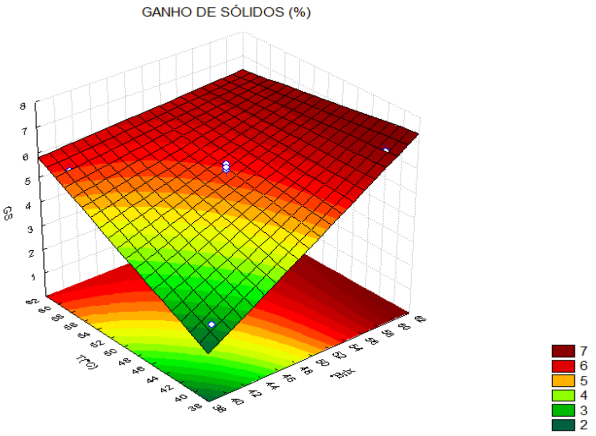


Figure 2. Response surfaces for the variables water loss, mass loss and solid gain of banana peels, as a function of sucrose concentration and temperature of the osmotic solution

According to the data evaluated in the factorial design 2^2, the sucrose concentration and the temperature in the process significantly influenced the response variables in the osmotic dehydration of banana peels. It was found that the increase of these factors increases the loss of mass and water in the system, and, consequently, reduces the water activity of the samples. During the experimental tests it was noticed that in 240 minutes of process there was a significant loss of water with greater aggregation of solids in the samples.

Figure 3 presents an optimized region of the factorial design in the contour surfaces of the response variables, water loss, mass loss and solids gain, identified by the upper right region, of a darker color, where the input variables concentration (°Brix) and temperature (° C) are more intense. Taking into account the effects observed during the osmotic dehydration of banana peels, and in view of the main objective of the food, which is to increase its shelf life, it was defined that assay 4 (60 Brix and 60 °C) would be the better condition of the process, as it presented higher concentrations of sucrose and temperature.

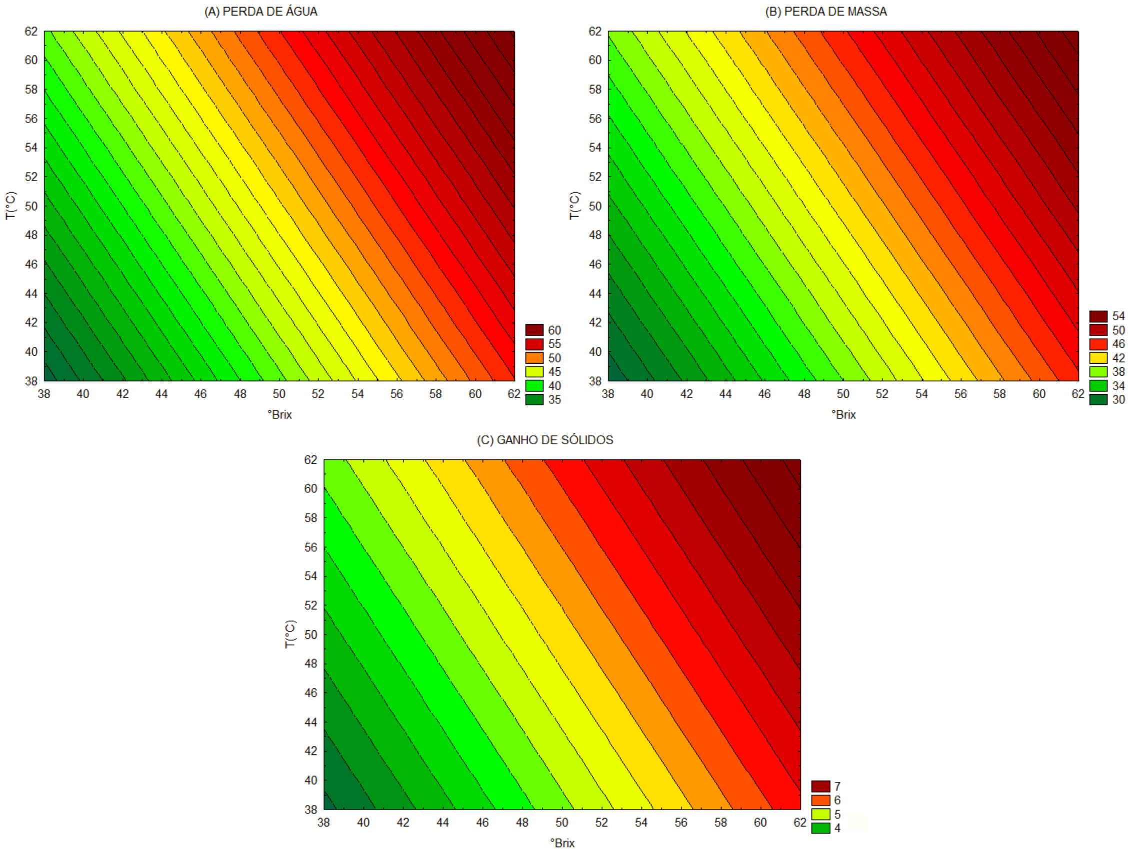


Figure 3. Contour curve of response variables in the optimized planning region

Table 7 shows the average results and the deviations of the physical-chemical parameters of the dehydrated banana peels in the best condition of osmotic dehydration (“optimized” condition).

Table 7. Characterization of dehydrated banana peel in the best condition of osmotic dehydration

Parameters	Mean ± Standard deviation
pH	5.27 ± 0.058
Total soluble solids (°Brix)	16.05 ± 0.050
TSS/TTA ratio	44.95 ± 0.050
Total titratable acidity (% ácido málico)	0.357 ± 0.027
Ascorbic acid (mg/100g de amostra)	1.395 ± 0.089
Water content (%b.u[1].)	43.14 ± 0.031
Ashes (%)	1.02 ± 0.015
Total solids (%)	56.86 ± 0.031
Reducing sugars (g/100g)	6.38 ± 0.165
Water activity (wA)	0.927 ± 0.001
L*	49.22 ± 0.095
a*	6.03 ± 0.023
b*	24.67 ± 0.044

Note: [1]wet base.

After the osmotic dehydration process, there was a decrease in the average value obtained for the pH in relation to fresh banana peels, 5.53 to 5.27 and an increase in the acidity content in terms of malic acid, from 0.168 to 0.357%. The same behavior was verified by Aragão *et al.* (2017) when monitoring the pH in the osmotic dehydration of slices of mangoes of the *espada* variety.

As expected, there was an increase in the content of soluble solids throughout the process due to the incorporation of solids. There was an increase in acidity in the slices of banana peels, so the ratio TSS / TTA generated greater results when compared to those obtained in fresh peels.

The ascorbic acid content varied between 1.415 and 1.395 mg.100g^{-1}. This reduction occurred due to the instability of the compound, which oxidizes easily in contact with oxygen and degrades with increasing temperature. The reduction in the ascorbic acid content in banana peels was not as significant compared to the study of the effect of osmotic dehydration conditions on araçá-pê raisins carried out by Paglarini *et al*. (2015), who found a loss of 87.3% in the conditions of 50 °Brix and 60 °C.

Analyzing the values of water content and water activity obtained at the end of the process, there is a considerable reduction in the water content of the samples, from 84.56 to 43.14%, and thus significantly altering the water activity from 0.966 to 0.927. Silva *et al.* (2015) obtained similar results of water activity when using forage palm (Opuntia fícus-indica Mill), under the same conditions studied (60 °Brix and 60 °C), of 0.991 for fresh samples and approximately 0.720 after osmotic dehydration.

Total solids ranged from 15.44 to 56.86%, for samples with and without osmotic treatment. Because of the reduction in water content, there was a greater aggregation of nutrients, allowing greater amounts of solids. The dehydrated samples had ash content lower than the values determined *in natura*. As found by Queiroz *et al*. (2008), this reduction is due to the solubility of the minerals present in the sample with the dehydrating solution.

Comparing the initial color parameters with those determined for the osmo-dehydrated banana peel slices, there is a reduction in the attributes of brightness (L*), red (a*) and yellow intensity (b*). It is worth noting that even with the heat treatment of enzymatic inactivation the slices darkened after the process, in terms of luminosity, from 56.09 to 49.22, in the intensity of red, with average values of 7.44 to 6.03, and a reduction in yellow intensity from 40.45 to 24.67.

The banana peels from the best condition of osmotic dehydration (assay 4 - 60 °Brix and 60 °C) were dehydrated in an oven with air circulation at 60 °C, to perform the drying kinetics curve and in Table 8 are the estimated values of the constants of the mathematical models of Page, Henderson & Pabis and Midilli are expressed, as well as the mean square deviations (MSD) and the coefficients of determination (R^2).

Table 8. Parameters, coefficients of determination (R^2) and mean square deviations (MSD) of the models adjusted to the drying kinetics of banana peels of the optimized condition

Model	Parameters				R^2	MSD
	k	n	a	b		
Page	0.7268	0.8491	-	-	0.9967	0.0102
Henderson & Pabis	0.6661	-	0.9627	-	0.9939	0.0156
Midilli	0.7690	0.8058	1.036	0.0004	0.9980	0.0299

Analyzing the obtained parameters, a small variation is observed for the mathematical constants “k”, “n” for the Page and Midilli models, which presented the highest determination coefficients. Corrêa *et al*. (2007), refers to the constants k and n as representing the effects of conditions external to dehydration and the internal resistance of the samples, respectively, for the drying process. Comparing the evaluated models, it can be said that the Page model was the one that best fitted the drying curve, with high R^2 and less quadratic deviation. Monteiro *et al*. (2020) when also performing the drying kinetics of osmotically dehydrated eggplant cubes, observed that the Page model was the one with the highest determination coefficients (R^2) and the lowest values of the chi-square function at all temperatures analyzed.

Figure 4 shows the convective drying kinetics curve of banana peels, at a temperature of 60 °C adjusted to Page's mathematical model.

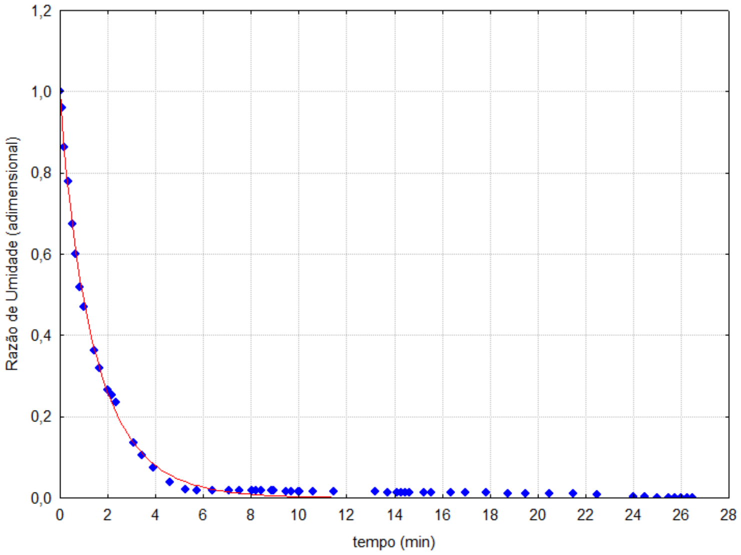


Figure 4. Drying curves of banana peels adjusted by the Page model

It can be seen through Figure 4, that the first 4 hours of drying were quite effective in reducing large amounts of water, then it appears that the curve reaches the most stable level of dehydration where the variation of water removed is minimal. The drying process proceeded for 26.5 hours until reaching constant mass.

The Fick's diffusion model was applied to determine the effective diffusivity (Def), considering the geometry of flat plates, obtaining a value of 2.2 x 10^{-8} m^2 s^{-1} and determination coefficient ($R^2 = 0.9898$). This low value of diffusivity during the drying of the peels, can be attributed to the fact that the sugar content absorbed by the samples prevents the outflow of greater water flow per unit of time. Aires *et al*. (2016), when performing the drying kinetics of osmotically dehydrated guavas at 40 and 50 °Brix, obtained diffusivity values ranging from 2.75 to 3.89 x 10^{-10} m^2 s^{-1}.

Table 9 shows the results of the physical-chemical parameters determined after the treatment of osmotic dehydration and convective drying, in the respective times: zero (considered the start of storage), fifteen and thirty days of storage.

Table 9. Average values of the physical-chemical parameters of banana peels after osmotic and convective dehydration during storage

Parameters	**Storage (days)**		
	0	15	30
pH	5.30 b	5.51 a	5.52 a
TSS (°Brix)	66.67 a	66.67 a	66.33 a
Ratio (TSS/TTA)	57.71 a	56.61 a	56.26 a
Total Titratable Acidity (% malic acid)	1.76 b	1.72 a	1.72 a
Ascorbic acid (mg/100g of sample)	1.47 a	1.37 ab	1.23 b
Water content (% w.b.)	16.67 a	16.72 a	16.74 a
Ashes (%)	1.72 a	1.73 a	1.73 a
Total Solids (%)	83.33 a	83.28 a	83.26 a
Reducing Sugars (g/100g)	6.87 a	6.36 b	6.30 b
Water activity	0.703 b	0.717 b	0.758 a
L*	38.19 c	38.60 b	39.26 a
a*	8.04 a	7.92 b	7.25 c
b*	19.61 a	18.74 b	17.36 c

Note: Means followed by the same letter on the lines do not differ statistically according to the Tukey test at the 5% probability level.

Table 9 shows an increase in pH and a reduction in the acidity of the sample between the beginning of storage and after the period of 15 days, with a statistically significant difference at a level of 5% probability, whose pH varied from 5.30 at 5.51 and acidity from 1.76 to 1.72%. There was no significant difference regarding these parameters during the period of 15 and 30 days of storage. According to Pegoraro *et al.* (2016), the reduction in the acidity of the fruits during the storage period occurs due to the degradation and volatilization of organic acids. Santos *et al*. (2015), when producing green banana flour, obtained a pH of 5.78.

Regarding soluble solids, there was an increase after dehydration, due to the incorporation of sucrose in the osmotic process. Evaluating the results obtained in comparison with Nunes (2017), who evaluated the properties of the banana flour of the Madeira variety, it is possible to verify that the peels after the osmo-convective process showed values close to those of the dehydrated fruit pulp flour, 71.12 °Brix.

There was no significant difference in the content of soluble solids during storage, which showed values from 66.67 to 66.73 °Brix. However, the reduction of the acidity of the product during storage caused an increase in the values of the ratio parameter, which ranged from 37.88 to 38.91. According to Morgado *et al*. (2019), the ratio parameter can express the degree of sweetness of the product and that it is common to increase this parameter during fruit storage, which occurs due to the reduction of acidity and an increase in the concentration of soluble solids.

In terms of ascorbic acid concentration, it can be said that the osmo-convective dehydration process preserved the quantities with respect to fresh, ranging from 1.415 to 1.47 mg.100g^{-1}. After the storage period, there was a decrease in the values of ascorbic acid, which according to Oliveira *et al.* (2015) is caused by oxidation reactions. Factors such as the applied dehydration method, storage time and packaging used directly influence the oxidation reactions to which the product is susceptible. Reis *et al*. (2017) observed an increase in the concentration of vitamin C after dehydration of acerola cherry. The same authors also found that the final concentration of this vitamin was lower when they used lower temperatures and longer periods of time, since the longer exposure time in drying degrades the nutritional constituents of food.

The osmotic process followed by convective drying was effective in reducing 80.3% of the water content and 29.41% in the water activity of peels *in natura*. The water content values did not differ statistically and varied from 16.67 to 16.74%, after 30 days. Lower values regarding water content (13.99 to 14.54%) were presented by Gonçalves *et al.* (2017) when performing the convective drying of banana peels, using temperatures of 55, 65 and 75 °C. Machado *et al.* (2019) when assessing the stability of the physalis pulp did not observe any significant difference in relation to the moisture content during the 120-day storage period. The value of water activity at the beginning of the storage period was 0.703 and increased to 0.758 at the end of dehydration, this difference being statistically significant.

There was no significant difference regarding the ash content during the storage of dehydrated banana peels, which showed values from 1.72 to 1.73%. Pagani *et al.* (2017) when analyzing flours obtained from drying sweet potatoes, they also found that the ash content of the samples was practically confirmed during their storage. Analyzing the results obtained for reducing sugars (RS), there is an increase in concentration after the osmo-convective process. In stability, only the average (0 days) differed statistically from its 15 and 30 day averages, with a reduction during the storage period. Considerable result compared to that found by Silva (2013), in banana peel flour, which presented a concentration of 5.75 (g/100g).

Evaluating the color parameters, it is observed that the slices darkened with the storage time, due to the increase in luminosity (*L), but also due to the red (+ a*) and yellow (+ b*) intensity values found. These parameters showed small variations, but differed statistically between the averages obtained. Similar behavior was observed by Aranha *et al.* (2017) when evaluating the stability of fruit flours during storage, the authors associated the color changes in the product to the enzymatic browning processes, Maillard reaction and factors such as changes in pH, acidity and storage temperature.

4. Conclusion

The banana peels used in the experiments had a high water content and reasonable amounts of carbohydrates and ashes. Under the conditions in which the assays were carried out, it can be concluded that the sucrose concentration and the temperature had significant effects on the process with assay 4, under the conditions of sucrose concentration (60 °Brix) and temperature (60 °C), providing greater water losses and incorporation of solids. The osmoconvective dehydration process resulted in a greater incorporation of total soluble solids and higher percentages of total solids in the peels.

Page's mathematical model showed the best fit to the experimental data, as it showed a coefficient of determination (R^2) greater than 0.99 and a low mean squared deviation (MSD). The effective diffusivity showed a coefficient of determination (R^2) greater than 0.98. The drying process provided product conservation, reducing the water content and activity. And the physical and physical-chemical parameters analyzed during the storage had small changes during the period of 30 days of storage.

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