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Drying of banana paste in rotatory dryer with inert bed

Secagem de pasta de banana em secador rotativo com recheio de inertes

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Summary

The objective of this research was to study the drying of “nanica” banana paste (variety belonging to the subgroup *Cavendish*) in a rotary dryer with an inert bed (RDIB). Preliminary tests were carried out to adjust the operational process parameters. An experimental design (central composite design) was used for the final drying experiments with the following variables: the drying time and the mass of paste fed into the dryer, and as responses: the moisture content and the yield in banana flour. As a result of the tests carried out according to the experimental design, a beige-coloured product, composed of banana powder and flakes was obtained with a characteristic banana aroma. A multiple linear regression of the experimental results was used to determine the influence of the process variables. The best operational conditions allowed for the manufacture of a product with 8.0% moisture content (wet weight base) and a flour production efficiency of 72.9%.

Key words: *Food powder; Pasty foods dryer; Additive; Banana flour; Production efficiency.*

Resumo

O objetivo desta pesquisa foi estudar a secagem de pasta de banana “nanica” (variedade pertencente ao subgrupo Cavendish) em secador rotativo com recheio de inertes (SRRI). Foram realizados testes preliminares para ajustar os parâmetros de operação do processo. Um projeto de experimentos (desenho composto central) foi aplicado para as experiências finais de secagem, tendo como variáveis: o tempo de secagem e a massa de pasta que alimentou o secador, e, como respostas: o teor de umidade e a produção de farinha de banana. Como resultado dos testes realizados de acordo com o projeto experimental, foi obtido um produto de cor bege, composto de pó e flocos de banana, e com aroma característico de banana. A influência das variáveis do processo foi investigada por meio de uma regressão linear múltipla para os resultados experimentais. A melhor condição operacional possibilitou um produto com 8,0% de teor de umidade (base úmida) e uma eficiência de produção de farinha de 72,9%.

Palavras-chave: *Alimento em pó; Secador de alimentos pastosos; Aditivo; Farinha de banana; Eficiência de produção.*

1 Introduction

Banana, besides constituting an expressive carbohydrate source (highly energetic), is also rich in potassium, sodium, phosphorus, chlorine, magnesium, sulphur, silicon, calcium; and the vitamins: A, B_1, B_2, C and B_3 (niacin), all essential for the human metabolism (PADOVANI, 1989). Mature green bananas are very rich in starch, which is resistant to a-amylase and glucoamylase due to its high degree of intrinsic crystalline structure (CHOO and AZIZ, 2010). Banana is well known as a tropical fruit that contains various antioxidants, especially catechin, epicatechin and gallocatechin. Abundant phenolic compounds were found in the Musa Cavendish variety (SOMEYA et al., 2002).

The world banana production is increasing almost yearly (FAO, 2008) and reached approximately 100 million metric tons in 2008 making bananas the fruit with the largest world production. However, the high water content of bananas makes them susceptible to mould growth. India, the world's largest banana exporter, reported postharvest losses of bananas as high as 35-45%, whereas Brazil, the world's second largest banana producer, producing approximately seven million tons a year, but only exporting 2%, reported a loss of approximately 40% due mostly to inadequate storage facilities during peak harvest times and industrial processing. The Nanicão variety (Musa cavendischii) is one of the most important crops in Brazil (CABRERA-PADILLA, 2003; CANO-CHAUCA et al., 2004; TRIBESS et al., 2009).

Banana flour is a low-cost ingredient for the food industry and an alternative to minimize banana wastage. The product can be used as an ingredient in other food formulations such as porridge, soups, for milk enrichment, in ice creams and other foods. It can also be used in bread making, where it is mixed in the proportion of 1/3 of banana flour to 2/3 of wheat flour (CABRERA-PADILLA, 2003).

Bananas are very susceptible to deterioration and a considerable amount of the fruit is wasted due to a lack of efficient preservation techniques (MASKAN, 2000). The preservation of bananas could reduce these losses and increase the world food supply. Drying, as a food preservation method, is one way of processing agricultural products after harvesting. The application of appropriate drying techniques is desirable in order to produce good-quality dried products (BAINI and LANGRISH, 2007).

Drying is a process involving simultaneous heat and mass transfer. The required amount of thermal energy to dry a particular product depends on many factors such as: the initial moisture content, desired final moisture content, temperature and relative humidity of the drying air, and the air flow rate (KARIM and HAWLADER, 2005).

Amongst the conventional dryers used to dry bananas the following stand out: the tray dryer, where the drying time is significant; the drum dryer, where the product does not present good uniformity in the drying; the spray dryer, with which a high quality product is obtained, although the capital investment and operational costs are significant, making its use for medium and small scale industries unfeasible (MASKAN, 2000).

During water removal by evaporation, many substances, including proteins and sugars, can be converted into an amorphous state. The temperature at which this transformation takes place is called the glass-transition temperature (T_g), which involves the transition of a liquid-like structured material from an "elastic" or "rubbery" state to a solid "vitreous" one. For the detachment of dried food materials from a glass surface to occur naturally without external aid, the moisture content of the film must reach values corresponding to those of the glass transition at the operational temperature (COLLARES et al., 2006).

The "rotary dryer with an inert bed" (RDIB) was developed in 1987 (Industrial Patent PI-8804812; Inventors: Burjaili, M. M; Finzer, J. R. D; Limaverde, J. R.). Dissertations and doctoral theses have been developed using this equipment, allowing for the publications cited in this paper. The current study used an improved version of the dryer with Request Invention Privilege-PI-060122-1, "dryer with inert and flowing by shearing action and heated by conduction" (Rights Privilege Uberlandia Federal University (2013), the inventors being those cited in the preceding patent). Several papers published in Journals and Proceedings used the different versions of this equipment. The dryer used for the production of banana powder is an important application, as an alternative to other dryers. Some studies have shown the need to use an adjuvant to facilitate separation of the dried product, and describe experimental results and efficiency. With these data it was possible to plan and carry out projects using the dryer to dry banana pulp.

The objective of this research was to study the drying of "nanica" banana paste (variety belonging to the subgroup *Cavendish*) in a rotary dryer with inert bed (RDIB). The RDIB is a technically viable alternative, since good quality powdered products have been obtained in the processing of other foodstuffs and wastes (FINZER et al., 1993; BURJAILI, 1996; MALDONADO, 2004).

2 Materials and methods

This paper describes the methodology used to dry the banana paste (with and without additive) in a RDIB, as well as presenting the results of the drying tests. The experiments were carried out using a factorial design that considered the influence of the variables and their interactions in the process yield.

2.1 Raw material and additive

The raw material used in this work was the "*nanica*" variety banana (subgroup *Cavendish*), showing 75% of ripening (yellow colour with green tips) and an average moisture content of 77.5% (wb), which is suitable for obtaining banana flour (MANICA, 1997). This stage corresponds to stage 5 of the banana ripening colour index (Figure 1, ALVES et al., 1999) according to Aurore et al. (2009).

The additive Dimodan HO-1, a distilled monoglyceride was provided by Danisco Brasil Ltda.

2.2 Banana paste preparation

Several paste preparation tests were carried out with different water ratios: 5%, 10%, 15% and 20% in relation to the raw banana mass. The objective was to obtain an easily pumped paste. The banana paste prepared with 10% water was shown to be a suitable paste for easy pumping. The paste was prepared as follows: selection of 75% ripe bananas; preliminary cleaning by washing in chlorinated water (4 ppm) at a temperature of 45 °C; five minutes of blanching in boiling water to reduce the number of microorganisms and inactivate the enzymes, followed by three minutes of cooling (DANDAMRONGRAK et al., 2002); removal of skins; cutting of fruits into approximately 0.02 m thick disk-like slices; immersion in 0.2% sodium bisulphite ($NaHSO_3$) solution for five minutes to avoid product oxidation (CHUA et al., 2001); drainage of the solution for five minutes; and finally grinding in a rotary knife mill. Addition of: i) water to reach a moisture content of 10% of the total pulp mass; ii) 1% of the additive "Du Pont- Dimodan HO-1", an emulsifier commonly used in bakery, oils, fats, dairy products, frozen desserts, confectionery and plastics, to improve texture, reduce viscosity and reduce sugar crystallization; and iii) 0.4% of ascorbic acid to avoid browning during the disintegration step (YAN et al., 2008).

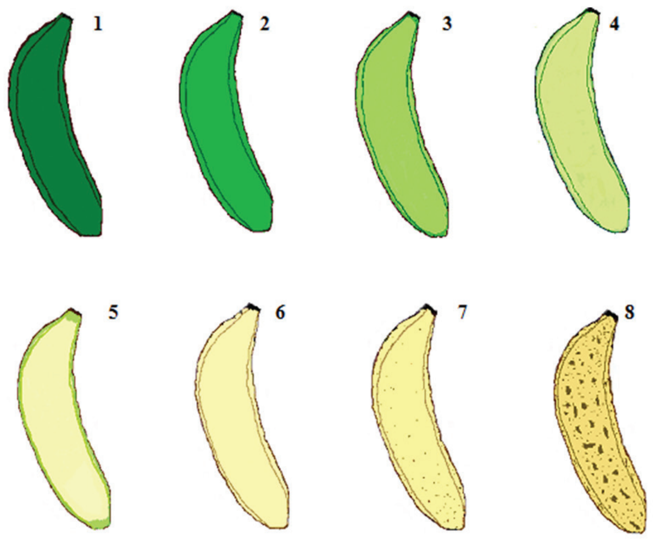

Figure 1. Ripening stages for Cavendish bananas as related to skin colour and changes in soluble starch and sugars: 1 Green; 2 Green with traces of yellow; 3 More green than yellow; 4 more yellow than green; 5 Yellow with green tips; 6 Completely yellow; 7 Yellow slightly mottled with brown; 8 Yellow with large brown areas (ALVES et al., 1999).

2.3 Drying tests

Preliminary qualitative coating and drying tests were carried out in a laboratory oven to select the inert materials to be used in the RDIB. Different materials were tested: stainless steel spheres, porcelain spheres and *"technyl"* cylinders. The porcelain spheres were chosen because they did not allow oxidation of the product and presented better heat transfer than the "*technyl*" cylinders. Furthermore, they permitted a homogeneous paste film on the surface during coating and before drying. The product showed oxidation when the stainless steel spheres were used.

2.3.1 Rotary dryer with inert bed

The banana paste drying tests were carried out in the R&D Laboratory of the Faculty of Chemical Engineering, Federal University of Uberlândia, Brazil. Figure 2a shows a schematic representation of the drying unit and its accessories. The dryer, built in stainless steel, consists of a 60 cm long cylindrical drying tunnel with a 25 cm inner diameter, divided into four longitudinal chambers. Axially, in the center of the tunnel, there is a hollow cylinder (inner diameter of 1.0 cm and wall thickness of 0.3 cm) for up to half of the length, with perforations through which the pasty material can pass. The diameter of the holes is 3.0 mm, distributed equidistantly along the supply section, with three holes in each chamber (see Figure 2b), Limaverde Junior (2000).

The banana paste was fed into the drying chamber that contained an inert bed (mass of 26 kg) of porcelain spheres (0.028 m to 0.030 m in diameter, and density of 3.630 kg/m^3). During the operation, the inert materials were covered with a layer of banana paste, which facilitated drying by increasing the contact surface between the material and the drying air. Rotation of the chamber provided a great number of collisions and shear stress (inert-inert and inert-wall), facilitating the mixing and drying of the paste.

The mechanical shocks and shear stress provide for grinding of the product during drying. The dry material was conveyed by the drying air and separated in a cyclone. The cyclone used possessed the following dimensions: height of the cylindrical section, 0.26 m; height of the conical section, 0.23 m; inner diameter of the cylindrical

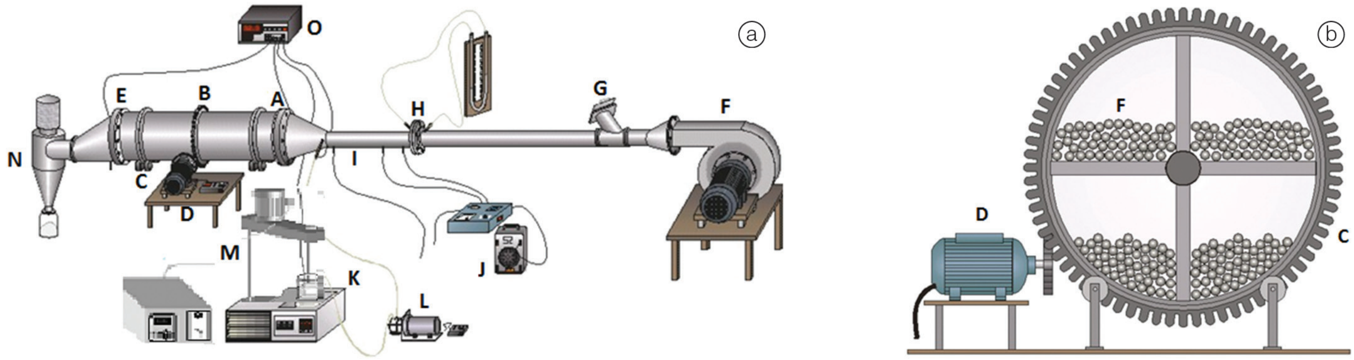

Figure 2. a) Schematic diagram of the Rotary Dryer with Inert Bed unit and its accessories, where: A (Steel ribbon), B (Gear), C (Rolling), D (Engine), E (Teflon ring), F(Blower), G (Air discharge), H (Orifice plate and Manometer), I (Electric resistance), J (Voltage transformer), K (Balance), L (Peristaltic pump), M (Agitator), N (Cyclone) and O (Temperature display); b) Schematic cross section of the Rotary Dryer with Inert Bed and its accessories where C (gear motor), D (Engine), F (spheres).

section, 0.16 m; diameter of the discharge pipe (top), 0.07 m; diameter of the discharge pipe (base), 0.04 m.

The rotational speed of the drying tunnel was maintained at 0.3 s^{-1}. Previous studies showed that the dryer presented good operational performance under these operational conditions (YOSHIDA et al., 2001). During the drying tests, the operational conditions were: air temperature of 70 °C (thus not exceeding the degradation temperature of the banana vitamins), air mass flow of 5.3 kg min^{-1} (allowing for a good heat transfer convection coefficient). These operational conditions allowed for easy discharge of in this operational condition (LIMAVERDE JUNIOR, 2000).

2.3.2 Experimental design

A central composite design (CCD) was used to design the banana paste drying tests considering two factors: feed paste mass (kg) and drying time (min). The statistical design consisted of a 2^2 factorial with four axial points and two centre points, giving a total of ten combinations. The yield and moisture content of the banana flour were considered as the dependent variables or responses of the design. The regression coefficients were determined and the data obtained analysed graphically using the Statistic® 8.0 software. The statistical significance of the regression coefficients was determined using the Student t-test and the model equation determined by the Fischer test. The proportion of variance explained by the model obtained was given by the multiple coefficient of determination, R^2 (BOX et al., 2005).

2.4 Characterization of the final product

The banana flour was characterized according to its moisture, crude protein, ash, lipids and total carbohydrate contents, which were determined according to the AOAC methods (HELRICH, 1992). The protein content (%N × 5.7) was determined by the Kjeldahl method. The moisture content was determined by oven drying for 4 h at 105 °C to constant weight. The ash was determined by dry combustion, and the free lipids by petroleum ether extraction, followed by evaporation to constant weight. The caloric values were calculated by summing of the specific calories of the carbohydrates, lipids and proteins (CABRERA-PADILLA, 2003). All sample determinations were carried out in triplicate.

3 Results and discussion

3.1 Preliminary drying tests in the RDIB

3.1.1 Drying test for banana paste without additive

The rotary dryer with inert bed was initially operated with the following operational conditions: feed 0.25 kg of banana paste (without additive) per cycle, with an initial moisture content of 79.5% (wwb). The feeding time per cycle was approximately 120 s. Each operational drying cycle lasted 35 min, of which the first 15 minutes were operated with a drying air temperature of 70 °C (relative humidity between 4.0-4.5%) and the remaining 20 min with a drying air temperature of 53 °C (relative humidity between 9.0-11.0%). Five consecutive drying cycles were carried out. The operational temperature of 53 °C allowed for the temperature of the dried banana to be kept below the glass transition temperature (Tg), so it was susceptible to dust generation (COLLARES et al., 2006). This operational condition was obtained experimentally. The air flow was kept constant at 8.8×10^{-2} kg s^{-1} for all cycles.

It can be observed from the results shown in Table 1 that under these operational conditions, an average flour yield of 2.92×10^{-3} kg was obtained, with an average moisture content of 9.26% (wwb). The average production efficiency was 5.2%, (ratio of powder separated in the cyclone to the amount of solids in the feed), the banana flour mass in each cycle was small and its colour was dark.

At the end of the last cycle the dryer was disassembled, and it was observed that a large amount of the material fed in was adhered to the drying drum. All the inert materials were covered with moist paste which adhered to the central axis and paddles.

3.1.2 Drying test of banana paste with additive

Technical information regarding the additive (Dimodan® HO-1) used in the drying of paste-like materials showed the easiness with which the dry materials detached from the surfaces. This is an indication that the production yield should increase with the use of the additive. Based on this information and on the preliminary tests, drying experiments using 1% Dimodan® were carried out under the same operational conditions. The results can be seen in Table 2, where an average flour yield of 28.3×10^{-3} kg with an average moisture content of 7.7% (wwb) can be observed, and an average production efficiency of 49.0%. The production of banana flour was practically stabilized after the first cycle. The product obtained, in the form of powder and flakes, presented a beige colour and a characteristic banana aroma. The colour of the final product changed due to browning, which has often been associated with the Maillard reaction, promoted by the use of high drying temperatures (BAINI and LANGRISH, 2007).

The Maillard reaction occurring in dehydrated foods during drying and storage is very important, due to the loss in nutritive value of the proteins involved in the reaction with the reducing sugars, and also because of the loss of sensory quality due to browning of the product, accelerated by the use of high temperatures (LEITE et al., 2007).

After the last cycle, the dryer was disassembled and a small amount of paste was observed adhered to the spheres and walls of the drying tunnel. This was an indication of production stability, and the dryer capacity was 0.25 kg banana paste per drying cycle. About 50% of the banana powder left through the top air outlet of the cyclone. Therefore the plants must use a filter bag to collect the fines.

Figure 3 shows a comparison of the banana flour yields with and without additive under the same operational

Table 1. Performance of rotary dryer without additive.

Cycle	Operational time (min)	Temperature of drying air (°C)	Flour yield (kg)×10³	Flour moisture % (wwb)	Production efficiency %
1	15	70.3	4.5	8.9	8.0
	20	53.3			
2	15	71.1	3.0	10.2	5.3
	20	53.3			
3	15	70.5	3.2	8.9	5.7
	20	54.0			
4	15	70.4	2.1	9.4	3.7
	20	54.9			
5	15	70.4	1.8	8.9	3.2
	20	52.9			

Table 2. Performance of the rotary dryer with additive.

Cycle	Operational time (min)	Temperature of drying air (°C)	Flour yield (kg)×10³	Flour moisture % (wwb)	Production efficiency %
1	15	70.5	21.7	7.7	37.7
	20	53.7			
2	15	72.1	31.6	8.0	54.7
	20	52.0			
3	15	72.1	27.2	7.6	47.3
	20	53.2			
4	15	72.7	30.4	7.7	52.7
	20	52.6			
5	15	72.2	30.4	7.7	52.7
	20	51.4			

conditions. A difference in the amount flour accumulated during production can be observed, and also the influence of the additive on the drying of the banana paste. This is fundamental for the technical viability of the process. For an operational processing time of 175 min using additive, the yield was approximately ten times greater than in the operation without additive.

3.2 Drying tests of the factorial design

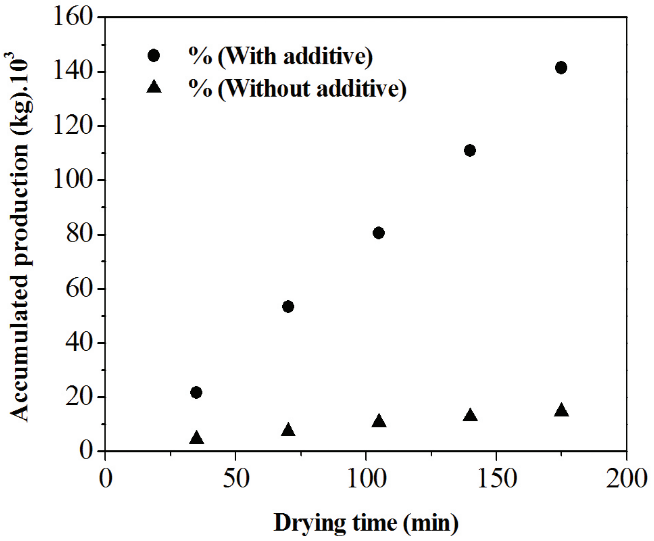

Figure 3. Comparison of the accumulated flour production with and without additive.

The results of the experiments of the factorial design - central composite design - are shown in Table 3. Each test corresponded to two drying stages. In the first stage the temperature of the drying air was maintained at 70 °C for the operational time shown in the table. In the second stage, in all the tests the drying air temperature was reduced to 53 °C and maintained for 20 min. Figure 4 presents a comparison of the accumulated banana flour yield as a function of the accumulated drying time (see Test 4), where the largest accumulated yield was 0.61 kg. Test 7 presents the smallest accumulated yield of banana flour (0.050 kg), since the drying time was insufficient.

3.3 Multiple regression analyses

Using the data presented in Table 3, a multiple regression was carried out for the responses of moisture content and flour yield. Table 4 presents the results for the multiple regression of the moisture content.

3.3.1 Moisture content

Equation 1 was used to represent the response function of the independent variables (BOX et al., 1985).

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} x_i x_j \quad (1)$$

The correlation obtained, Equation 2, relates the banana flour moisture as a function of the coded independent variables.

Table 3. Results of the drying tests, with the conditions of each experiment.

Test	Codified variables X1	Codified variables X2	Total paste load (kg)	Drying time 1st stage (min)	Product moisture content (%)	Banana flour yield (kg)
1	–1	–1	0.25	15	7.7	0.028
2	–1	1	0.25	45	7.3	0.036
3	1	–1	0.75	15	11.0	0.054
4	1	1	0.75	45	8.0	0.122
5	–1.0781	0	0.23	30	7.5	0.034
6	1.0781	0	0.77	30	10.0	0.088
7	0	–1.0781	0.50	14	10.6	0.010
8	0	1.0781	0.50	46	8.3	0.083
9	0	0	0.50	30	9.5	0.086
10	0	0	0.50	30	9.3	0.085

Table 4. Regression results for the moisture content.

Factors	Parameters	Student t test	Level of Significance	Standard Deviation
Constant (β_0)	9.3993	79.0465	0.000000	0.118909
X_1(AP)	1.0784	11.3597	0.000092	0.094935
X_2(TS)	–0.939	–9.8910	0.000180	0.094935
X_1^2(AP^2)	–0.7468	–5.1418	0.003640	0.145250
X_1X_2(AP.TS)	–0.6375	–5.3403	0.003089	0.119375
R^2 = 0.98	$F_{C(4.5)}$ = 70.46	F_T(0.01)= 11.39		

This model was obtained considering only the influence of parameters with significance levels in the Student t test above 10%, thus some insignificant interaction parameters are absent in the regression equation.

$$U = 9.40 + 1.08X_1 - 0.94X_2 - 0.75X^2_1 - 0.64X_1X_2 \quad (2)$$

were U is the moisture content (%), and X_1 *and* X_2 are coded independent variables for the paste feed and drying time respectively.

The parameters with significance levels above 10% in the Student "t" test, showing they were non-relevant variables, were removed from the equation. Considering the values for the significance level in the "software Statistics", the parameter of X_2^2 (which is the coefficient of X_2^2) was –0.17, but with a significance level of 28.5%, which is higher than 10%, so a quadratic factor was eliminated from Equation 2.

The determination coefficient (R^2) for the model was 0.98. The response surface shown in Figure 5 illustrates the effects of the process variables on the banana flour quality as a function of the moisture content (U) When the paste feed (X_1) increased and the drying time (X_2) decreased, the moisture content increased. The maximum region on the response surface for the moisture content corresponded to the largest banana paste feed level. The condition where the moisture content was within the expected value, that is, below 8%, corresponded to the region where the banana paste feedi was below 0.33 kg.

3.3.2 Flour production

Table 5 presents the results for the multiple regression of the banana flour yield.

Equation 3 presents the correlation found to represent the production of banana flour as a function of the coded independent variables. This model was obtained only considering the influence of significant factors ($p < 0.05$), thus some insignificant interaction parameters are absent in the regression equation.

$$P = 0.074 + 0.027X_1 - 0.024X_2 - 0.018X^2_2 + 0.015X_1X_2 \quad (3)$$

were P is the banana flour yield (kg).

The value of the determination coefficient (0.91) indicates the quality of the fit obtained for the experimental data for the response of banana flour yield. Figure 6 presents the response surface that illustrates the effects

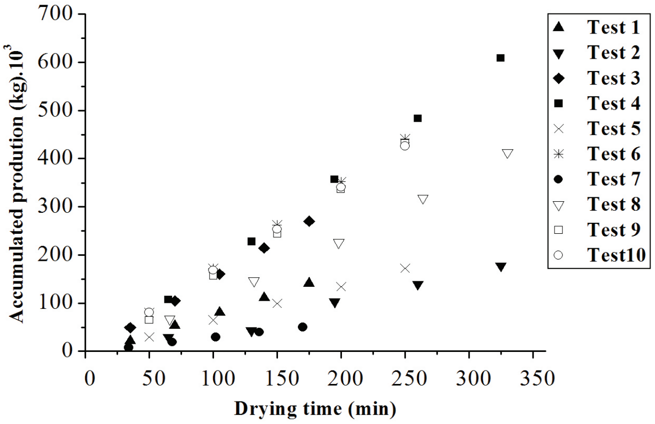

Figure 4. Comparison of the accumulated productions for the ten tests of the factorial design (central composite design).

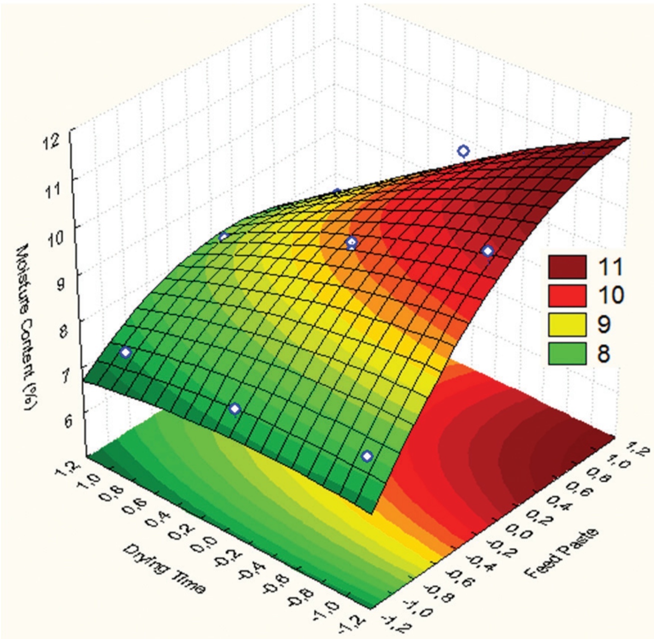

Figure 5. Response surface for the moisture content as a function of X_1 and X_2.

Table 5. Regression results for banana flour yield.

Factors	Parameters	Student t	Level of Significance	Standard Deviation
Constante(β_0)	0.0741	10.0749	0.000165	0.007354
X_1(AP)	0.0269	4.5805	0.005945	0.005871
X_2(TS)	0.0242	4.1293	0.009091	0.005871
X_2^2(AP^2)	–0.0181	–2.0181	0.099612	0.008983
X_1X2(AP.TS)	0.0152	2.0534	0.095229	0.007383
R^2 = 0.90	$F_{c(4.5)}$ =11.58	F_T(0.01)= 11.39		

Table 6. Banana flour quality (results for test 4).

Parameters	Value determined	Gross Michel species*	Unidentified species*
Moisture content (wwb) (%)	8.03	8.50	5.00
Ash content (%)	2.63	2.00	3.06
Total carbohydrate content (%)	65.66	82.20	79.90
Lipid content (%)	2.81	1.05	2.30
Protein content (%)	3.79	2.00	4.98
Caloric value (kcal/100 g)	303.10	346.50	283.00

*Data published by Martin et al. (1990).

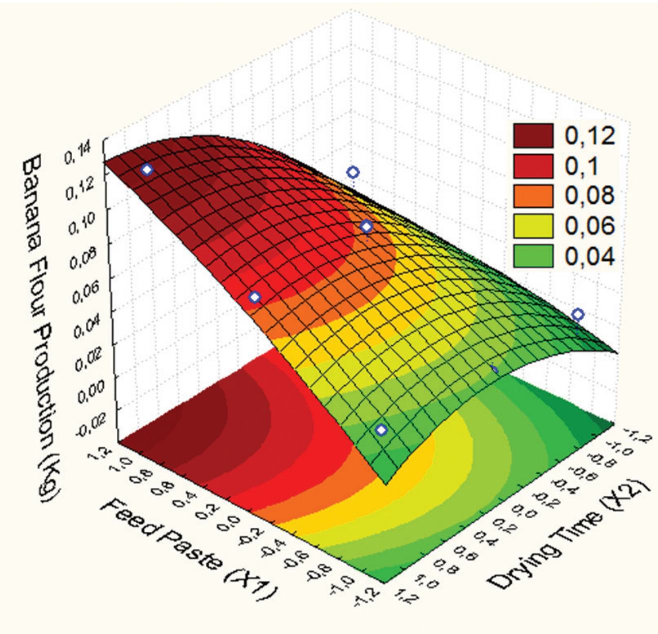

Figure 6. Response surface for the banana flour yield as a function of X_1 and X_2

of the process variables on the banana flour quality with respect to flour yield (P). It was shown that when the paste feed (X_1) increased, the production increased; whereas a decrease in drying time (X_2) produced a decrease in the yield. The maximum region for flour production corresponded to the largest levels of paste feed and drying time.

3.4 Banana flour characterization

The product obtained in Test 4 was used for characterization of the banana flour, because it presented better characteristics, such as colour, aroma, production and mainly the moisture content (6 to 8%). The results of the physicochemical analyses shown in Table 6 compare favourably with the reference for the composition of banana flour published by Martin et al. (1990). Comparing the results obtained for the banana flour obtained in the current work with suitable data, it was found that they were similar, especially for the moisture content, which is a decisive quality parameter for this type of product. Similar results for moisture content were obtained by Tribess et al. (2009) for green banana flour of the same variety used in this work. Analyzing the data in Table 6, it can be seen that the caloric value of the banana flour obtained was within the range of values published in the literature.

4 Conclusions

The highest production efficiency for the dried banana in the rotary dryer occurred with the addition of Dimodan® HO-1 to the paste. The production of the powder without the additive in the paste was not technically viable. The fit of the empirical equations for moisture content and flour yield indicated that about 98% of the data variability could be explained by the equation proposed for the response of moisture content and 91% for the banana flour yield. Analyzing the results obtained, the best operational conditions for the drying of banana paste in the rotary dryer with inert bed were: drying air flow rate of 8.8×10^{-2} kg s^{-1}; drying air temperature operating for 45 minutes at an average temperature of 70 °C and for 20 min at an average temperature of 53 °C; banana paste feed rate of 4.2×10^{-3} kg s^{-1}; total banana paste feed of 0.75 kg per cycle. Under these operational conditions, an average yield of 0.122 kg of banana flour was obtained, corresponding to a powder production efficiency of 72.9%. The product obtained was in the form of powder and flakes, beige in colour and with a characteristic banana aroma. The moisture content obtained, of 8.0% (wwb), was within the range established for this type of product (6 to 8%).

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