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DETERMINATION OF THE DRYING VARIABLES FOR DEHYDRATION OF BANANA PULP SHEETS (*Musa paradisiaca L.*)

Nestor Enrique Cerquera, Eduardo Pastrana and Jennifer Katiusca Castro
Universidad Surcolombiana, Avenida Pastrana, Neiva, Huila, Colombia
E-Mail: cerquera@usco.edu.co

ABSTRACT

Bananas are, after coffee, Colombia's most important agricultural product. Post-harvest losses and the emergence of new markets for processed products; make it convenient to the introduction of technologies to its most efficient use. In this paper, banana pulp (*Musa paradisiaca* L.) is characterized and the drying variables are determined to obtain dried pulp sheet. To achieve this, equipment for testing static drying is designed and built, and banana pulp is characterized by determining: moisture content, soluble solids, pH and acidity. The drying curves, with forced air, for different air speeds (178.3 m.min-1, 206.1 m.min-1 and 234.1 m.min-1) and different temperatures (50°C, 55°C, 60°C and 65°C) are obtained, finding that an air velocity of 231.4 m.min-1 and a temperature of the drying air of 65°C, are the most suitable conditions for dehydrating banana pulps used under the experimental conditions. The behavior of the dried pulp sheet obtained, in relation to their conservation parameters, is satisfactory; microbiological counts are within acceptable ranges for dehydrated products which are favoured by the low water activity reached in the dried product.

Keywords: drying curves, drying time, pulp sheet, dehydrating equipment.

1. INTRODUCTION

Bananas usually deteriorate rapidly after harvest. Dehydration or drying is an alternative way to preserve the quality and add value to bananas. Drying or dehydration is one of the oldest techniques documented in the literature to reduce high perishability of agricultural products, by reducing the moisture content thereof with a corresponding reduction in water activity. Among the techniques of drying or dehydration may be mentioned the drying processes by natural convection, generally performed in ovens by forced convection with different types of dryers and by vacuum, which apply to a variety of agricultural products, such as grains, fruits and vegetables as presented by Park, Yado and Brod (2001), Arévalo-Pinedo and Murr (2005); Leite, Mancini and Borges (2007); Parra-Coronado, Roa-Mejía and Oliveros-Tascón (2008), Corrêa*et al*. (2008), Borges *et al*. (2008, 2011).

The control parameters may vary according to the process but, in general terms, temperature, air speed and size of the food are the parameters that have a greater influence on the rate of drying, as well as in the final moisture content, contraction or shrinkage of the product and the features that are related to the preservation and quality of the food. Different authors such as Queiroz and Nebra (2001); Park *et al*. (2001); Nicoleti, Telis-Romero and Telis (2001); Lewicki and Pawlak (2003), Demirel and Turhan (2003); Krokida*et al.* (2003); Karim and Hawlader (2005); Nguyen and Price (2007); Parra *et al*. (2008); Thuwapanichayanan, Prachayawarakorn and Soponronnarit (2008) and Borges *et al.* (2008, 2011) indicate that high drying rates are achieved when the temperature or air speed rises due to an increase in the diffusion coefficient of moisture, reaching the desired moisture content more quickly, with a corresponding reduction of the drying time.

A reduction in product dimensions can be observed during the drying process due to changes in the microstructure of the fresh tissue promoted by thermal stress and mainly by moisture removal according to Lewicki and Pawlak (2003), Demirel and Turhan (2003), Kingsly*et al*. (2007), Borges *et al*. (2008). This phenomenon, known as shrinkage or contraction, has been discussed in several papers, finding a different behavior for each food studied, for each geometry and, for each drying system, but in general terms the volume of the product evolves in the same way than the moisture content does as referred by Talla*et al*. (2004), Kingsly*et al*. (2007) and Borges *et al*. (2008).

Several banana drying experiments have been conducted, using different methods, such as solar drying, Smitabhindu, Janjai and Chankong (2008), vacuum drying, Swasdisevi*et al.* (2009), over a foam mat drying, Thuwapanichayanan*et al*. (2008), spray drying, Evelin, Jacob and Vijayanand (2007), among others. The most common technique used to preserve the banana is the hot air drying, as mentioned by Queiroz and Nebra (2001), Demirel and Turhan (2003), Karim and Hawlader (2005) and, Nguyen and Price, 2007).

Borges *et al* (2011) studied the influence of temperature, relative humidity and the shape of the solid in the drying of bananas. Bananas into cylinders and discs were dehydrated by natural convection on drying trays at temperatures of 40 ºC and 70 ºC, finding that the temperature had a positive influence on the rate of drying. In relation with the form of samples, banana disks showed significantly higher drying rates.

Nguyen and Price (2007) studied the influence of temperature, relative humidity and thickness of cylindrical disks of banana (1 or 2 cm) on the drying process with air, finding that the initial moisture content has a marked influence on the drying kinetics. The temperatures of the drying air varied from 30 ºC to 70 ºC, with a constant air speed (1 $m.s^{-1}$). The initial moisture content of banana was 2.91 dry basis moisture content (db) (74.7% wet basis moisture content (wb) and decreased to 0.16 db (14% wb). The study indicates that the increase in temperature

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significantly improves the rate of drying (moisture loss) and reduces the drying time.

Karim and Hawlader (2005) used a tunnel dryer for drying bananas. Bananas had a density of 980 kg m^{-3} (0.98 g cm^{-3}) and an initial moisture content of 4.0 db (80 % wb). Drying air temperatures ranged from 40 °C to 60 °C, with air velocities varying between 0.3 and 0.7 m s^{-1}. The results indicate that high drying rates are achieved when the temperature or the speed of the drying air rises.

Demirel and Turhan (2003) dried, in a cabinet type dryer, banana slices of 2 mm thickness and 25 mm diameter. Treatments were: without any treatment, treated with sodium bisulfite and, treated with ascorbic acid / citric acid. The drying air temperatures varied from 40 °C to 70 °C with an average air speed of 3.3 m s^{-1}. They found that pretreatment and increased temperature, lowered browning and color change. The authors indicated that banana samples shrank due to drying, decreasing its size with reduced moisture content; they also reported that there were two periods of time with diminished drying rate and, that the drying rate increases with increasing temperature.

Queiroz and Nebra (2001) dried, with hot air, whole bananas and found that the drying time diminished when the temperature of the drying air increased; they report that for an air temperature of 60 °C the drying time was about 35 h. They indicated that whole bananas reduced about 43 to 47% of its original diameter during hot air drying, when moisture was reduced from 3.2 db (76.2% wb) to 0.3 db (23.1% wb).

According to FAOSTAT (2011), world production of bananas in 2009 was close to 299 million tons, the largest producers were India (9.03%), the Philippines (3.02%), China (3.01%), Ecuador (2.6 %) and Brazil (2.27%); Colombia ranked ninth (0.7%).

In 2009 Colombia had 74,112 ha grown in bananas, for an annual production of 2'020.390 metric tons (FAOSTAT, 2011); from the cultivated area, 44,000 ha are in the states of Antioquia and Magdalena, which are the major producing areas of the country (AUGURA, 2011). Banana exports represent 3.0% of total Colombian exports, 35.0% of agricultural products other than coffee and 0.4% of gross domestic product (GDP). The Colombian bananas, whose exports are mainly destined to the European Union and to the United States, produced 96.75 million cases in 2009, for a total of 1'885.000 metric tons exported for an approximate value of US $ 705.6 million (AUGURA, 2011).

The Colombian fruit sector has had, in recent years, an unusual growth, mainly due to the industrialization of the fruit and the growing demand for natural products, such as fruit pulps, processed pulps and nectars (Cerquera, 2006). The fruit pulps are sold fresh, refrigerated and / or as frozen concentrates, or dehydrated. Dehydration techniques that use low temperatures are of static type and use forced air or vacuum drying ovens. Dewatering systems by direct contact are also used, such as the equipment that uses high temperature rollers that run continuously. However, this procedure greatly affects the nutritional content and organoleptic and functional characteristics of the pulps (Barbosa and Vega, 2000).

Colombia has a great export potential for its production of tropical fruits, which are prized abroad. In particular, the market for "laminated dehydrated pulps" is a niche that not is covered by other countries, because they are products of relatively recent development, whose target market are countries like Germany, United States, Canada and, as alternative way, to Spain, Japan and the Andean Community. Therefore, the objective of this study was to characterize banana pulp and to determine drying variables, suitable to obtain sheets of dehydrated banana pulps, such as drying time, speed and temperature of drying air.

2. MATERIALS AND METHODS

2.1 Raw material

For different tests good quality bananas (*Musa paradisiaca* L.) were used. Bananas were in maturity stages 4 and 5 according to the banana skin color chart reported by Dadzie and Orchard (1997). For the different assays, banana pulp mixed with orange pulp, in a ratio of three parts of banana pulp by a part of orange pulp (juice), was used. The addition of orange pulp to the banana pulp aimed to reduce browning, by increasing the concentration of citric acid present and, the consequent reduction in pH. Obtaining and conservation of selected fruit pulp was held at the facilities of the Pilot Plant of the Institute of Science and Food Technology, ICTA, of Universidad Nacional de Colombia (National University of Colombia) - Bogotá.

For dehydration of pulps, it was designed and built an equipment (Figure-1), in which the recommendations given by Perry *et al*. (1997) were considered, with which it is sought that the speed of the drying air was between 120 and 300 m min^{-1} in order to improve the heat transfer coefficient and to eliminate stagnant air bags. Additionally, the trays were metallic, to improve heat transfer and handling, and that the clearance between trays were greater than 38 mm.

2.2. Characterization of banana pulp

The characterization of fresh banana pulp was made prior to drying tests. To do this, three replicates (10 fruits each), to which there were determined the moisture content using a vacuum oven, applying AOAC OM934.06 (Official Methods of Analysis of Official Analytical Chemists, 1998); the titratable acidity was determined by titration according to the AOAC OM942.15 standard; the determination of soluble solids was performed using a refractometer KIKUCHI (0 to 30 °Brix), pH was determined using the modified method of Pearson (1993).

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Figure-1. Static drying equipment built for testing the dehydration process of fruit pulp in sheets.

2.3. Obtaining drying curve

The following conditions for fruit pulp drying, by static layer, were evaluated: temperatures were 50, 55, 60 and 65 °C, in combination with hot air three speeds: 178.3 m min^{-1} (0.151 Air Flow m^3 s^{-1}), 206.1 m min^{-1} (0.175 m^3 s^{-1}) and 234.1 m min^{-1} (0.198 m^3 s^{-1}); two replicates for each combination temperature-air speed (twelve treatments) were evaluated, for a total of twenty-four trials, according to a completely randomized factorial arrangement experimental design. About 500 g pulp were placed in each of the trays, previously coated with cling film, in order to easily remove the product once dried. Moisture loss of pulps was evaluated over time. From the resulting data, the different drying curves were built and the drying rate calculated.

In each test, four trays of fruit pulp were dehydrated simultaneously, taking the weight of two of them every hour, to obtain the weight corresponding to a final moisture content of 11% bh (0.123 db). The moisture content was determined using a vacuum oven (AOAC OM934.06); water activity was determined directly with a Novasina BSK device; titratable acidity was determined following the AOAC OM942.15 standard, and a micrometer was used to determine the thickness of the sheet of fruit.

With the information from the statistical analysis applied to the drying tests, the results of sensory tests analyzed by the statistical T test (nonparametric method ranges) and, the other features evaluated for the final product, the most favourable conditions for dehydration were determined.

2.4. Proximal and Microbiological Analysis

In order to evaluate the final product, the proximal and microbiological analyses were done in accordance to the guidelines of the Official Methods of Analysis of Official Analytical Chemists (1998). In the proximal analysis performed were determined: moisture (AOAC OM934.06), fat (OM920.39 AOAC), crude fiber (AOAC OM96209), protein (AOAC OM954.01), minerals (AOAC OM942.05), carbohydrates (by difference), and energy (kcal.$100^{-1}g^{-1}$) by indirect calculation using the Atwater Factor. Microbiological analyses the samples were: total coliforms (MPN), aerobic mesophilic count (CFU.g^{-1}) and counting of fungi and yeasts (CFU.g^{-1}).

3. RESULTS AND DISCUSSIONS

3.1 Characterization of fresh pulp

Physico-chemical characterization of fresh pulp. The average characteristics of fresh banana/orange pulp, hereinafter banana pulp, used in the tests referred to drying, are presented in Table-1. The values of moisture content (79.9% bh) are within the values reported by Nguyen and Price (2007) (74.4% wb) and Karim and Hawlader (2005) (80% wb). The value of pulp density (1.05 g.cm^{-3}) is close to that reported by Karim and Hawlader (2005), which is 0.98 g.cm^{-3}. The pH (4.10) is close to that reported by Muriel (2013) (4.21); soluble solids (18.5 °Brix) are close to those reported by Muriel (2013) (23.3 °Brix); and Acidity (0.62%) is close to that reported by Muriel (2013) (0.74%).

Table-1. Physico-chemical parameters of fresh banana pulp.

Parameter	Banana/Orange
Pulp yield (%)	52,00
Water in the pulp (% bh)	79,90
Density (g.cm^{-3})	1,05
pH	4,10
Soluble solids (ºBrix)	18,50
Acidity (% Citric Acid)	0,62

Proximate analysis of fresh banana pulp showed mean values of 0.0% fat content value close to that reported by Tonna, Afam and Godwin (2013) (0.2%) and Aurore *et al*. 2009 (0.3%).; carbohydrates 19.3%, value close to that reported by Tonna *et al*. (2013) (22.2%), Aurore *et al*. 2009 (21.8%) and, Colombian Family Welfare Institute (ICBF) 2005 (20.5%).; minerals 0.5%, 0.45% crude fiber and 77.2 kcal energy.

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3.2. Drying curves

With the experimental information, curves and drying times for different treatments were obtained. In these curves it is possible to observe two clearly defined areas (Figures-2, -3 and -4), where the first one corresponds to a high rate of drying with a marked slope, with the approximate turning point corresponding to the moisture of 0.5 db (33% bh), and thereafter the second zone, where the drying rate decreases rapidly, behavior that is similar to that reported by Demirel and Turhan (2003) for banana slices and, for different agricultural products by Brooker, Bakker-Arkema and Hall (1992). For banana pulp, this turning point is reached for the air temperature of 50 °C at 7 hours of drying time, for 55 °C is reached between 6 and 7 hours, for 60 °C between 5 and 5.5 hours and, for 65 °C between 4.5 and 5 hours. It is noted that the time at which the inflection point was reached in each of the temperatures, was smaller as the speed of the drying air was increased.

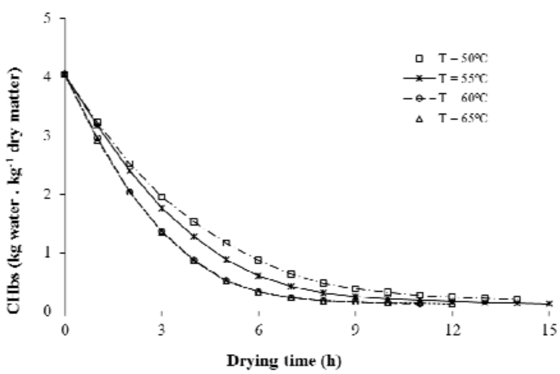

Figure-2. Drying curve for banana pulp with a speed of 178,3 m.min^{-1} at different temperatures of drying air.

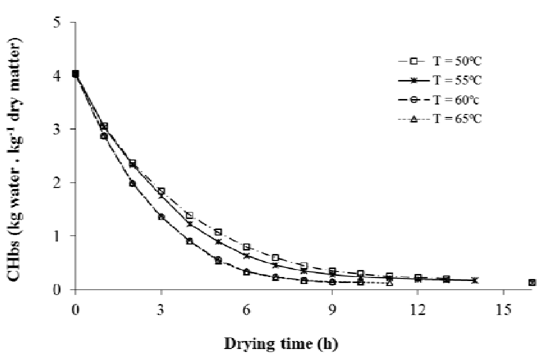

Figure-3. Drying curve for banana pulp with a speed of 206,1 m.min^{-1} at different temperatures of drying air.

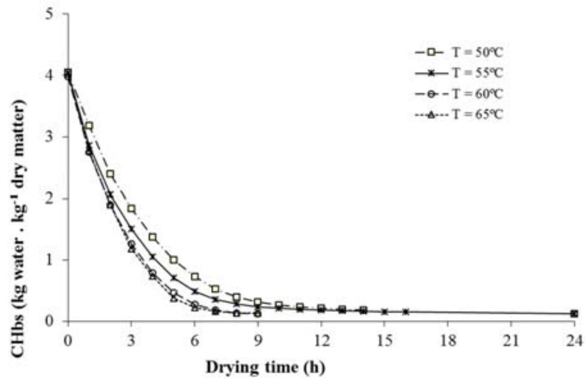

Figure-4. Drying curve for banana pulp with a speed of 234,1 m.min^{-1} at different temperatures of drying air.

For the different treatments differences are observed in drying time, finding that increasing the air temperature while maintaining its speed constant, drying time decreases, yielding lower drying times with the highest temperature (65 ºC) and higher speed used drying air (234.1 m. min^{-1}), which is confirmed by analysis of variance, factorial ANOVA, in which the values of p-value (Pr> F) were zero (0), which it means that significant differences for drying times regarding the conditions of temperature and air flow used were presented, being smaller at higher temperatures and air speeds (Table-2), this is consistent with findings, for drying bananas, by different authors such as Queiroz and Nebra, (2001), Demirel and Turhan (2003), Nguyen and Price (2007) and Borges *et al*. (2011), and such other researchers for different agricultural products as (Brooker *et al.*(1992), Parra *et al.*(2008), Castro, Rodríguez and Vargas (2008), Borges *et al*. (2008), Bala*et al*. (2010) and Icier *et al*.(2010).

3.3. Characterization of the dehydrated pulp

The pH of the dehydrated pulp presented a similar value to the fresh pulp, while titratable acidity showed an increase of 530% compared to the acidity of the fresh pulp, with a value of 3.287 with 0.067 as standard error. The water activity of the dehydrated pulp had an average value of 0.484 with a standard error of 0.008, varying between 0.40 and 0.60, allowing consider the dehydrated banana obtained, with this procedure, has a good storage behavior and very low probability of being attacked by pathogenic microorganisms. The statistical analysis of moisture content, water activity and acidity, showed that among them there are no significant differences.

The sheets of dehydrated pulps had an average thickness of 1.7 mm, being the initial thickness of the fresh pulp of approximately 10 mm, with a 83% reduction in the thickness of the sheet of banana pulp, which is consistent with the behavior found by such different authors for drying bananas with hot air as Queiroz and Nebra (2001), Talla*et al*. (2004) and Demirel and Turhan (2003). Yields for dehydrated banana obtained were

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22.3% compared to fresh pulp and 11.2% compared to the fresh fruit including the peels.

Proximate analysis of the banana dehydrated pulps presented average values of moisture content of 9.4% wb (db 0.104) with 10.1% maximum wb (0.112 db), fat 0.0%, crude fiber 1, 8%, protein 4.0%, 3.6% minerals, carbohydrates 81.2% and 341 kcal. As shown, the final moisture content is below 12% wb (db 0.136), which corresponds to the expected moisture content to ensure preservation of the product in prolonged storage. Moreover, an increase in the content of crude fiber, proteins, minerals and carbohydrates, due to the concentration of the total soluble solids, resulted in a product with higher caloric content; this behavior in the increase of constituents by reducing the water content is consistent with the found by Aurore, Parfait and Fahrasmane (2009).

3.4. Microbiological analysis.

Microbiological counts of total and fecal coliforms, mesophilics, fungi and yeast, for both fresh pulps (two samples (Table-3)) and the dried product (four samples (Table-4)), were performed. According to the resolution 7992 of 1991 of the Colombian National the Ministry of Health (1991), the count of total coliforms and mesophilics is within the allowable ranges for pasteurized and frozen pulps: MPN <3 and 20000 CFU g^{-1}, respectively, as well as the presence of fungi and yeasts for frozen pulps: 1000 CFU g^{-1}. Therefore, it can be inferred that the procedure used to obtain pulps was adequate and within the standards for unpasteurized fresh pulps.

Table-2. Drying times to bring the banana pulp to a final moisture content of 11% bh (0,123 db).

Experiment Nº	Drying temperature (ºC)	Air speed (m min^{-1})	Drying time (h)
1	50	178,3	24
2	50	178,3	24
3	50	206,1	24
4	50	206,1	24
5	50	234,1	24
6	50	234,1	24
7	55	178,3	16
8	55	178,3	15
9	55	206,1	24
10	55	206,1	24
11	55	234,1	23
12	55	234,1	24
13	60	178,3	11
14	60	178,3	10
15	60	206,1	9
16	60	206,1	10
17	60	234,1	8
18	60	234,1	9
19	65	178,3	12
20	65	178,3	10
21	65	206,1	10
22	65	206,1	11
23	65	234,1	8
24	65	234,1	8

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Table-3. Microbiological Analysis results for fresh, unpasteurized, banana pulps.

Microbiological analysis	Banana 1	Banana 2
MPN total coliforms g^{-1}	< 3	< 3
MPN total coliforms g^{-1}	$11x10^1$	$22x10^2$
Fungi and yeast count CFU g^{-1}	$17x10^1$	$33x10^1$

MPN g^{-1} = most probable number per gram, CFU g^{-1} = Colony forming units per gram.

Table-4. Microbiological analysis results for banana dehydrated pulps.

Microbiological analysis	Banana 1	Banana 2	Banana 3	Banana 4
MPN total coliforms g^{-1}	< 3	< 3	< 3	< 3
MPN total coliforms g^{-1}	10	< 10	< 10	< 10
Fungi and yeast count CFU g^{-1}	120	330	120	120

MPN g^{-1} = most probable number per gram, CFU g^{-1} = Colony forming units per gram.

For the case of dehydrated fruit pulp, there is no written legal regulation in Colombia, which is why the results of this research were compared with Resolution No. 4241 of April 1991 of the Colombian Ministry of Health (1991), "By which the characteristics of spices and vegetable seasonings are defined, and health and quality standards for these products and their mixtures are dictated". According to this standard for food with moisture close to 10%, in Article 4, it states that the permitted range for fecal coliforms MPN is 4-40 per gram and, fungi and yeasts from 3000 to 5000 CFU per gram. Based on this article, samples of dehydrated banana pulps are within permitted ranges for human food. These results are consistent with the conditions of low water activity obtained in these products, which allows the control of growth of most pathogenic microorganisms and make good use of the dehydrated product storage.

CONCLUSIONS

a) Drying curves obtained for banana pulp, have the normal tendency for drying of agricultural products, with a region of high drying rate and one with a decreasing rate, noting that the time where the inflection point has been reached is lower as the temperature and flow rate of drying air increases. Beyond the inflection point, considerable differences in drying time are observed, showing that air speed decreases with an increase of temperature.
b) It is found that the drying air temperature of 65 °C and an air speed of 231, 4 $m.min^{-1}$ are the most suitable experimental conditions for dehydrating banana pulps.
c) The water activity of the dehydrated product anticipates a good product storage stability and very low probability of attack of pathogens.
d) The behavior of the obtained products related to their conservation parameters are satisfactory, since microbiological counts are within acceptable ranges for dehydrated products, mainly due to the low water activity reached in the dehydrated product.

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