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Solar drying of 'Prata' bananas

Álvaro Gustavo Ferreira da SILVA[1], Renata Ranielly Pedroza CRUZ[2*], Wennia Gomes MOREIRA[3], Maria Angelica Freitas PEREIRA[3], Adriano Sant'Ana SILVA[3], Franciscleudo Bezerra da COSTA[3], Ana Marinho do NASCIMENTO[3], Pahlevi Augusto de SOUZA[4], André Luiz dos Santos TIMOTEO[5], Wellington Souto RIBEIRO[2]

Abstract

The banana is one of the most consumed fruits in the world, but it has little shelf life due to its high water activity. Drying is able to increase shelf life and pre-treatments can optimize the process. The objective was to study the solar drying kinetics and evaluate the effect of pre-treatments on the drying kinetics and physico-chemical quality of 'Prata' bananas. The drying was carried out in a solar dryer and the pre-treatments consisted of immersing the samples in solutions of water, citric acid (1%) and lemon juice (10%). Water loss, drying kinetics, mathematical models and physical-chemical and colorimetric characteristics of fresh and dried bananas were evaluated. The drying rate was higher at the beginning and stabilized after 20 hours. The mathematical model of Midilli and Kucuk was the one that best fit the experimental data. The water content, ascorbic acid and the parameters L *, b *, C * and h ° reduced after drying. Reducing sugars and a * coordinate increased and the acidity was not changed with drying. The solar drying of 'Prata' bananas is a sustainable and economical way to make a product available with a longer shelf life.

Keywords: citric acid; lemon; *Musa* sp.; post-harvest quality.

Practical Application: Solar energy contributes to adding value to 'Silver' bananas in the snack format.

1 Introduction

The banana is one of the most consumed fruits worldwide (Gomes et al., 2014). Its high consumption is due to its nutritional and energetic value, as it is rich in starch and sugar, vitamins A and C, potassium, calcium, sodium and magnesium (Ranjha et al., 2020), in addition to the pleasant taste, coming from groups ester, alcohols and phenolic compounds (Saha et al., 2018).

The high-water content is a critical factor that reduces the time of storage and transportation of fruits in general. Drying is a method capable of prolonging shelf life, reducing the weight for transportation, reducing storage space and controlling microbiological and enzymatic reactions responsible for the degradation of bananas (Ranjha et al., 2020). Drying also provides a greater diversity of products, for example, bananas, powder, snacks and as part of breakfast cereals (Saha et al., 2018).

Drying using solar energy has been widely used as a way to replace fossil fuels used in conventional processes (Lingayat et al., 2017). The thermal energy absorbed by the solar collector material is transmitted and trapped inside, maintaining its high temperature (Samimi-Akhijahani & Arabhosseini, 2018). The solar dryers use in agriculture for food dehydration and crops is efficient and economical, without harming the environment (Maia et al., 2017).

Chemical, thermal or osmotic pretreatments are usually applied before drying to improve the sensory and/or physicochemical dry foods characteristics (Nyangena et al., 2019). Organic acids can be used to reduce enzymatic browning, decrease the unwanted intermediates formation and provide sucrose inversion, which guarantees greater sweetness and better technological properties to the product.

The objective was to study the solar drying kinetics and the effect of pre-treatments on the physicochemical characteristics of dehydrated 'Prata' bananas.

2 Material and methods

2.1 Obtaining and processing raw materials

Bananas, 'Prata' variety, were purchased in the municipal market of Pombal, Paraíba, Brazil, selected in advanced maturation stage (yellow with brown spots, according to Von Loesecke ripening scale), plummeted, washed under running water, sanitized in chlorinated solution (150 ppm for 15 minutes), rinsed, peeled and sliced manually into 1.0 cm thick slices.

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[1] *Programa de Pós Graduação em Ciência de Alimentos, Faculdade de Engenharia de Alimentos, Unicamp, Campinas, SP, Brasil*
[2] *Programa de Pós-Graduação em Fitotecnia, Departamento de Agronomia, Universidade Federal de Viçosa, Viçosa, MG, Brasil2*
[3] *Programa de Pós-Graduação em Horticultura Tropical, Centro de Ciências e Tecnologia Agroalimentar, Universidade Federal de Campina Grande, Pombal, PB, Brasil*
[4] *Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Norte, Campus Currais Novos, Currais Novos, RN, Brasil*
[5] *Curso de Agronomia, Departamento de Agronomia, Universidade Federal de Viçosa, Viçosa, MG, Brasil*
*Corresponding author: renataranielly426@gmail.com

Three hundred grams of sliced bananas were distributed in three containers, with one hundred grams each, and subjected to three treatments: immersion in water (T1); immersion in citric acid solution 1% (T2) and immersion in lemon solution 10% (T3), for 15 minutes, and evenly distributed in the collectors for solar drying (Figure 1).

2.2 Solar drying

The drying was carried out in a direct exposure handmade solar dryer. The equipment was black pressed wood made. The collector and the drying chamber were covered by 2 mm glass plates. The heat-absorbing body of the solar collector was produced with zinc and painted with black ink.

Prior to the start of the drying process, the dryer was exposed to solar radiation for 30 minutes for preheating. The trays containing the slices were arranged randomly inside the dryer from 07:00 to 17:00 for two days, totaling 20 hours of sun exposure. The slices were weighed every hour and drying was completed after obtaining constant mass in three consecutive weighing on an analytical balance. The dried slices were packed in high density polypropylene packaging, vacuum sealed, covered with aluminum foil and stored in a refrigerator (8 °C). This process was carried out three times and on different days. The temperatures in the collector and in the drying chamber (1a, 1b and 1c) were collected during drying using a digital skewer thermometer (Mundial, WT-1, ± 0.1 °C).

2.3 Analysis of the drying process

Water loss and final water content were determined. From them, the water content ratio (RWC) (Equation 1), necessary to obtain the drying curves, were calculated. The mathematical models of Midilli and Kucuk (Equation 2), Page (Equation 3), Logarithmic (Equation 4), Newton (Equation 5), Henderson and Pabis (Equation 6) and Two terms (Equation 7) were applied. The determination coefficient (R2) (Equation 8), the relative mean deviation (DQM) (Equation 9) and the chi-square (X2) (Equation 10) were adopted as evaluation criteria.

$$RWC = \frac{(U_t - U_e)}{(U_0 - U_e)} \tag{1}$$

$$RWC = a * exp\left(-k * t^n\right) + b * \tag{2}$$

$$RWC = a * exp\left(-k * t^n\right) \tag{3}$$

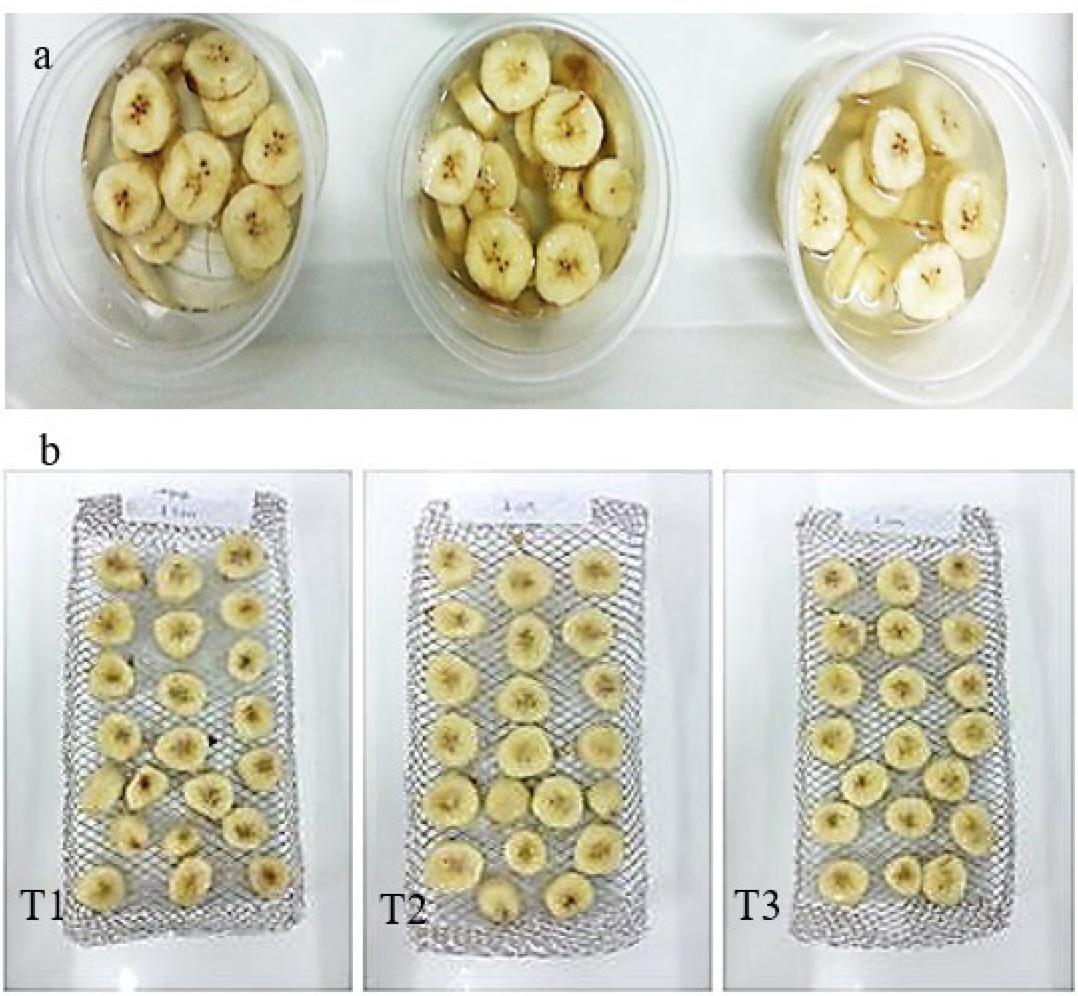

Figure 1. a) Treatments with water, citric acid and lemon, b) slicing the trays.

$$RWC = a * exp(-k * t) + c \tag{4}$$

$$RWC = \exp(-kt) \tag{5}$$

$$RWC = a * \exp(-kt) \tag{6}$$

$$RWC = a * exp(-t) + b * exp(-t) \tag{7}$$

$$R^2 = \frac{\sum_{i=1}^{N}\left[(RWC_{exp} - \overline{RWC_{pre}})(RWC_{pre} - \overline{RWC_{pre}})\right]^2}{\sum_{i=1}^{N}\left((RWC_{exp} - \overline{RWC_{pre}})\right)^2 \sum_{i=1}^{N}\left((RWC_{pre} - \overline{RWC_{exp}})\right)^2} \tag{8}$$

$$DQM = \sqrt{\frac{\Sigma\left(RWC_{pre} - RWC_{exp}\right)^2}{N}} \tag{9}$$

$$X^2 = \frac{1}{N-n}\sum_{i=1}^{N}\left(RWC_{pre} - RWC_{exp}\right)^2 \tag{10}$$

Where, (1): Ut, Ue and U0 are, respectively, the water content as a function of time, water content in the balance and initial water content, expressed in dry basis (mass H2O dry mass^{-1}); (2): U is the humidity [dry basis] and t is the drying time [hours]; (3, 4, 5, 6, 7 and 8): t is the drying time [hours], k is drying constant, n, b, c and a are parameters of the models; (9, 10 and 11): RWC_{pre} is the ratio of the water content predicted by the equation, RWC_{exp} is the ratio of the experimental water content, $\overline{RWC_{pre}}$ is the average of the ratio of experimental water content, N is the number of observations made during the experiment and n is the number of constants in the model.

2.4 Physicochemical analysis

Fresh and dehydrated bananas were evaluated:

Water content (WC)- determined by dehydration in an electric oven (SOLAB®) at 70 °C until constant mass (Instituto Adolfo Lutz, 2008);

Total titratable acidity (TA)- determined by titration with 0.1 N NaOH and 1% phenolphthalein alcohol as an indicator. The results were expressed in malic acid content (Instituto Adolfo Lutz, 2008);

Ascorbic acid (AsA)- determined by the reduction of 2.6 dichlorophenolindophenol acid 0.2% and oxalic acid 0.5% as an extracting solution (Association of Official Analytical Chemists, 1997; Benassi & Antunes, 1998);

Reducing sugars (RS)- determined by the reduction of glucose by the compound 3,5-dinitrosalicylic acid (Vasconcelos et al., 2013);

Color- determined using the parameters luminosity (L), chroma (C) and hue (h) with the aid of a colorimeter (Konica Minolta, CR-10) previously calibrated on a white surface (Bible & Singha, 1997).

2.5 Statistical analysis

The results of the physical-chemical evaluation were subjected to Analysis of Variance (ANOVA) and the means compared by Tukey's test at 5% significance by the software Assistat®, version 7.7 (Silva et al., 2002).

3 Results and discussions

The maximum temperature reached in the collector, in the drying chamber and outside the dryer (room) was 89.8, 70.0 and 40.0 °C, respectively (Figure 2).

The temperature in the collector was higher due to the structure of the dryer that allows greater sun exposure at these points which are subject to greater sun exposure. At all times, the temperature in the solar dryer was considerably higher than the ambient temperature because the infrared waves pass through the glass, with low thermal resistance, and are absorbed by the dryer's internal coating. The coating consists of metallic material painted with black paint, which intensifies the transmission and absorption of heat. After absorption, infrared waves of lower frequencies are emitted by the dark coating, but do not pass through the glass to the outside, making the inside of the dryer warmer.

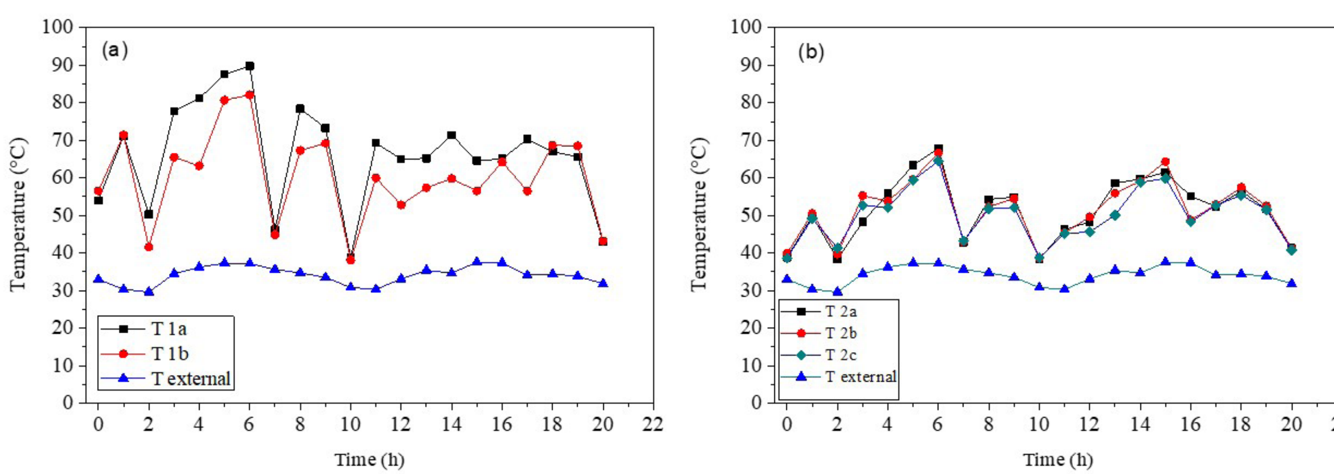

Figure 2. Temperature readings in (a) solar collector and (b) drying chamber.

The drying kinetics of sliced bananas did not differ between treatments, it was higher in the first eight hours and reduced until the end of the process. The average drying time was 20 hours and did not differ between treatments (Figure 3).

RWC varies with the intensity of water diffusion from the inside of the food to its surface and reduces with decreasing water content and increasing drying time (Mewa et al., 2019). The rate represents the drying speed and shows that the water loss started low, increased over time, reached a maximum value (between 3 and 5 hours of drying) and decreased to a constant value (at 20 hours of drying) (Al-Ali & Parthasarathy, 2019). One curve is presented for each drying day, totaling two curves. The drying rate starts low due to the low initial temperature of the bananas and increases sharply with the absorption of heat, which leads to increased pressure and speed of drying. The phase of decreasing rate occurs in response to the reduction in the water content of the surface, until the moisture of the product is in equilibrium with the humidity of the air, rendering the drying rate null. The bananas pretreated with citric acid and lemon solution reached the peak of the drying rate more quickly, indicating that the treatments provided greater water migration to the surface at the beginning of the process. However, there was no difference in the final drying time between treatments.

The mathematical model of Midilli and Kucuk showed a better fit to the kinetic data of the solar drying of bananas (Table 1).

All applied mathematical models adequately describe the drying performed, with R^2 values above 0.99 and DQM less than 0.02. However, the Midilli and Kucuk model was the one that most adjusted because it presented the highest R^2 values and the lowest DQM values in relation to the others. With respect to drying constant k, the treatment that resulted in the greatest increase in drying speed was T2, immersion in a 1% citric acid solution.

The water content (WC) and ascorbic acid (AsA) reduced after drying and did not differ between treatments. The content of reducing sugars (RS) increased with drying and differed between treatments. The ash contents and total acidity (TA) did not change with drying and did not differ between treatments (Table 2).

The reduction in TA due to exposure to hot air, regardless of treatment, occurs in the first hours through the rupture of cell membranes. Free water interacts with macromolecules, increasing the amount of water bound. However, under the continuous action of hot air, water gradually migrates outwards, reducing the total amount of water in the food (Li et al., 2019). TA did not

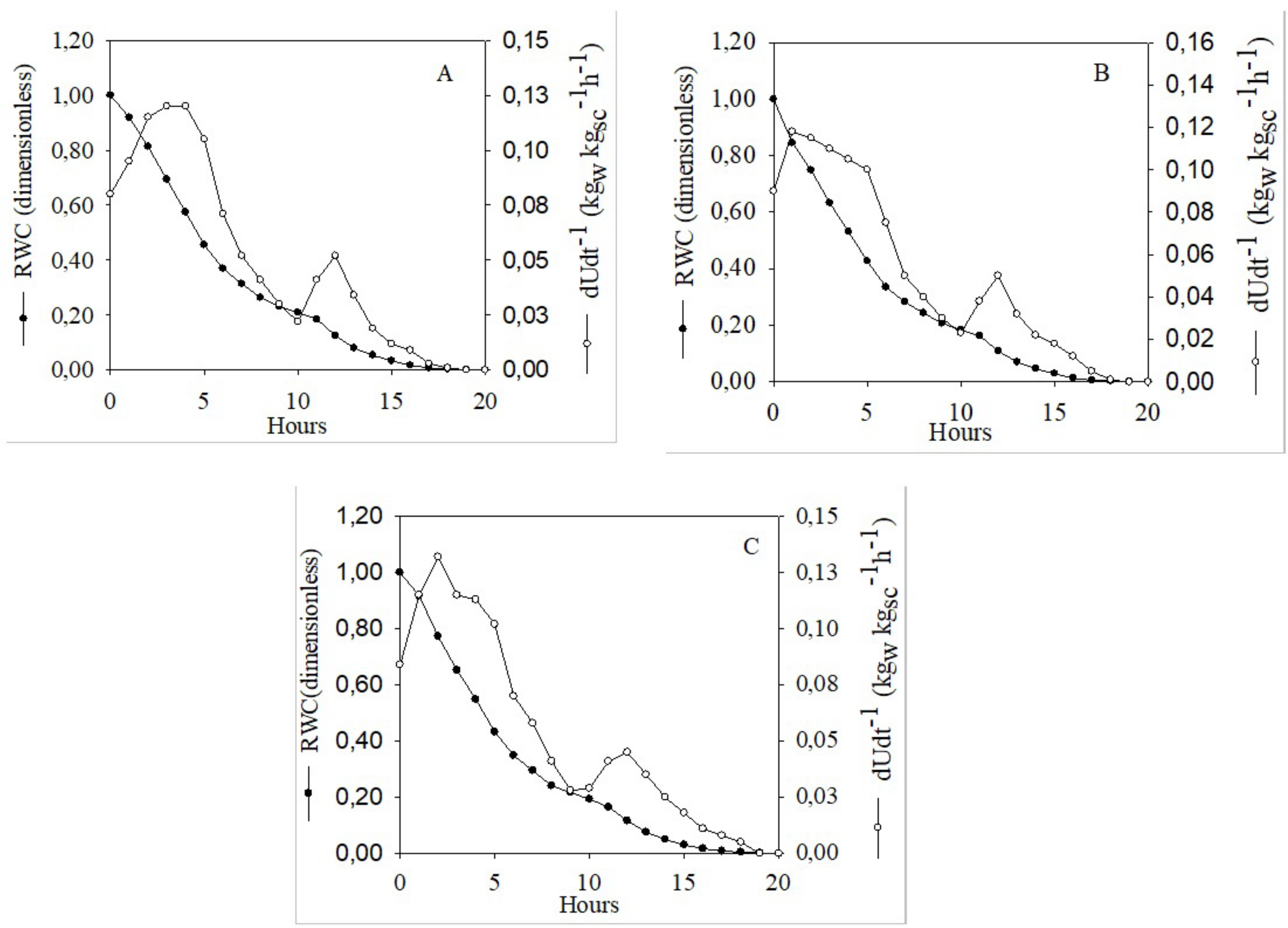

Figure 3. Ratio water content (RWC) and drying rate (dU/dt) of 'Prata' bananas pretreated in water (a), 1% citric acid (b) and 10% lemon solution (c).

vary in fresh and dried bananas, regardless of treatment. Malic, citric and oxalic acids are the main organic acids in banana pulp, with malic and citric acids being present in greater quantities during the advanced maturation stage (Etienne et al., 2013). Drying did not cause significant changes in the TA of bananas, even those submitted to pretreatments. AsA content decreased after drying in all treatments, due to its sensitivity to high temperatures (Dhakal et al., 2018) and oxygen (Aguilar et al., 2019). The RS content increased with drying, mainly in bananas treated with 1% citric acid solution and 10% lemon solution, due to the inversion of sucrose through acid hydrolysis.

The luminosity (L*), red/green coordinate (b*), chromaticity (C*) and hue angle (h°) decreased after drying and did not differ between treatments. The yellow/blue coordinate (a*) increased with drying and did not differ between treatments (Table 3).

The reduction in L* and b* parameters and an increase in a * parameter is the result of non-enzymatic browning reactions, which form dark pigments such as melanoidins, by the maillard reaction, or caramel, by caramelization (Qiu et al., 2019). The C* coordinate refers to saturation and the h ° coordinate to hue. The reduction of the coordinates C* and h° indicates that the color of the bananas has become more neutral (less saturated/pigmented) and with a tonality approaching the reddish after drying. All the coordinates analyzed indicate that the drying of the bananas promoted loss of yellowish white placement and formation of a grayish red pigmentation.

Table 1. Parameters of the models applied to represent the drying of banana slices in the studied treatments.

Model	Treatment	Parameters						R^2	DQM	X^2
		a	k (min^{-1})	c	n	b	y			
Page	T1	-	0.093	-	1.277	-	-	0.996	0.021	0.001
	T2	-	0.131	-	1.154	-	-	0.997	0.019	0.000
	T3	-	0.111	-	1.221	-	-	0.996	0.019	0.000
Logarithmic	T1	1.141	0.139	-0.093	-	-	-	0.995	0.023	0.023
	T2	1.077	0.153	-0.067	-	-	-	0.997	0.015	0.015
	T3	1.111	0.152	-0.070	-	-	-	0.996	0.019	0.019
Midilli and Kucuk	T1	0.108	0.108	-	1.188	0.002	-	0.997	0.018	0.018
	T2	0.997	0.142	-	1.078	-0.002	-	0.998	0.014	0.014
	T3	1.016	0.127	-	1.138	-0.001	-	0.997	0.016	0.016
Newton	T1	0.163	-	-	-	-	-	0.980	0.037	0.045
	T2	0.177	-	-	-	-	-	0.990	0.030	0.030
	T3	0.171	-	-	-	-	-	0.986	0.037	0.037
Henderson and Pabis	T1	1.081	0.175	-	-	-	-	0.986	0.037	0.037
	T2	1.037	0.183	-	-	-	-	0.992	0.027	0.027
	T3	1.068	0.182	-	-	-	-	0.990	0.030	0.030
Two terms	T1	0.540	0.175	-	-	0.540	0.175	0.986	0.037	0.037
	T2	0.518	0.183	-	-	0.518	0.183	0.992	0.027	0.027
	T3	0.534	0.182	-	-	0.534	0.182	0.990	0.030	0.030

T1 = immersion in water, T2 = immersion in 1% citric acid solution, T3 = immersion in 10% lemon solution.

Table 2. Physico-chemical characterization of fresh and dried bananas in a handmade solar dryer.

Treatment	WC	Ash	pH	TA	AsA	RS
In natura	69.1 ± 0.2 a	1.0 ± 0.0 a	5.1 ± 0.1 a	1.3 ± 0.0 a	15.9 ± 1.2a	46.6 ± 1.5d
T1	14.6 ± 0.0 b	1.0 ± 0.0 a	5.3 ± 0.1 a	1.0 ± 0.0 a	5.9 ± 0.9 b	54.7 ± 1.5c
T2	14.5 ± 0.0 b	1.0 ± 0.0 a	4.9 ± 0.1 a	1.4 ± 0.0 a	4.2 ± 0.6 b	63.9 ± 1.9a
T3	14.1 ± 0.0 b	1.0 ± 0.0 a	5.1 ± 0.1 a	1.0 ± 0.0 a	4.2 ± 1.5 b	55.9 ± 1.7b

Means followed by the same letter in the lines do not differ by Tukey's test ($p < 0.05$). T1 = immersion in water, T2 = immersion in 1% citric acid solution, T3 = immersion in a 10% lemon solution, TA (% wet basis), ash (%), TA (% malic acid), AsA (mg 100g-1); RS (%).

Table 3. Coloring of fresh and dried bananas in a handmade solar dryer.

Tratamento	L*	a*	b*	C*	h°
In natura	72,5 ± 7,0 a	0,2 ± 1,3 b	28,3 ± 2,4 a	28,3 ± 2,4 a	89,7 ± 2,5 a
T1	32,1 ± 0.6 b	5.5 ± 0.1 a	16.9 ± 0.9 b	17.8 ± 0.9 b	72.2 ± 1.0 b
T2	35.9 ± 2.6 b	5.2 ± 0.4 a	19.0 ± 1.5 b	19.8 ± 1.4 b	74.6 ± 1.8 b
T3	32.7 ± 2.3 b	4.9 ± 1.8 a	16.4 ± 2.4 b	17.2 ± 2.4 b	73.3 ± 6.5 b

Averages followed by the same letter in the columns do not differ by Tukey's test ($p < 0.05$). T1 = immersion in water, T2 = immersion in 1% citric acid solution, T3 = immersion in 10% lemon solution.

4 Conclusions

The Midilli and Kucuk model was the one that best represented the drying process. 'Prata' bananas can be dried in a handmade solar dryer for 20 hours maintaining the quality of the product. The use of an antioxidant solution based on natural lemon acids guarantees a natural product that is easy to apply. Banana dehydration in a direct radiation solar dryer is a viable, sustainable, practical, simple, functional and inexpensive means.

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