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Effect of pretrature with ultrasound in convention drying kinetics of bananas (*Musa paradisiaca*)

Efecto del pretratamiento con ultrasonido en la cinética de secado convencional de banano *(Musa paradisiaca)*

Yesenia Campo-Vera[1*], Mauricio Eduardo Contreras[2], Sandra Liliana Flórez[3], Lucero Villamizar[4]

[1*]*Magíster en Ciencia y Tecnología de Alimentos, yesenia.campo.vera@gmail.com, ORCID: 0000-0003-4658-8113, Instituto Superior de Educación Rural, Pamplona, Colombia.*

[2]*Magíster en Ingeniería Industrial, mauriciocontreras.docente@iser.edu.co, ORCID: 0000-0003-1931-6278, Instituto Superior de Educación Rural, Pamplona, Colombia.*

[3]*Tecnólogo en Procesos Agroindustriales, sandralilianaflorez1987@gmail.com, ORCID: 0000-0002-9695-7821, Instituto Superior de Educación Rural, Pamplona, Colombia.*

[4]*Tecnólogo en Procesos Agroindustriales, lucerovillamizar11@gmail.com, ORCID: 0000-0002-3874-9477, Instituto Superior de Educación Rural, Pamplona, Colombia.*

	ABSTRACT
Keywords: Bananas, Conservation, Convection drying, Humidity, Ultrasound.	The use of ultrasound in food processing has increased in the last decade due to the reduction in times, temperatures, microbial and enzymatic inactivation, extraction of components of great interest to different industries; without altering or modifying its nutritional or organoleptic value during the transformation processes of raw materials into products with added value. Considering itself, a green technology by not causing a negative impact on the environment. In this work, the effect of US pretreatment (40KHz/130W/30°C /10, 20 and 30 min) on convective drying at 60°C / 2m / s of banana (*Musa paradisiaca*) was evaluated. A diffusion model was used to describe the drying kinetics and to quantify the influence of the US on the effective diffusivity of water. Observing that the US significantly increased (p> 0.05) the drying speed in all the samples treated with an average reduction of 31% in the drying time with respect to the control treatment; reaching a weight loss of 77% with respect to the initial weight (3.8 to 0.9 g.). The exponential model is the most adequate to predict the experimental curves of banana drying and showed that the application of US increased both the effective diffusivity and the mass transfer coefficient, as corroborated by the values of the explained variance of 98.5 a 99.3%.
	RESUMEN
Palabras clave: Plátanos, Conservación, Secado por convección, Humedad, Ultrasonido.	El uso del ultrasonido en el procesamiento de alimentos se ha incrementado en la última década debido a la reducción en tiempos, temperaturas, inactivación microbiana y enzimática, extracción de componentes de gran interés para diferentes industrias; sin alterar o modificar su valor nutricional u organoléptico durante los procesos de trasformación de las materias primas en productos con valor agregado. Considerándose, una tecnología verde al no causar impacto negativo al medio ambiente. En este trabajo se evaluó el efecto del pretratamiento con US (40 KHz/130W/30°C /10, 20 y 30 min) en el secado convectivo a 60°C/2m/s del banano (*Musa paradisiaca*). Se utilizó un modelo difusional para describir las cinéticas de secado y cuantificar la influencia del US en la difusividad efectiva de agua. Observando que el US incrementó significativamente (p>0.05) la velocidad de secado en todas las muestras tratadas con una reducción promedio del 31% en el tiempo de secado con respecto al tratamiento control; alcanzando una pérdida de peso del 77% respecto del peso inicial (3.8 a 0.9 g.). El modelo exponencial es el más adecuado para predecir las curvas experimentales de secado del banano y mostró que la aplicación de US aumentó tanto la difusividad efectiva y el coeficiente de transferencia de masa, como corroboran los valores del porcentaje de varianza explicada de 98.5 a 99.3%.

Introduction

Drying is a classic method for food preservation, it has the advantage of decreasing the weight for transport and reducing space requirements for storage [1], [2]. Drying increases, the stability of foods by reducing the water activity, limiting the microbiological action, and the physicochemical changes that occur during storage [3], [4]. Conversely, drying results in a loss of product quality due to the structural and biochemical changes; depending on the drying technique and temperature [5].

The most conventional drying technique which uses low temperatures is lyophilization, where higher quality products can be obtained; but with very long process times, longer than those of hot air drying [6], [7]. Drying is a complex process in which a simultaneous transfer of matter and energy is produced, and modeling becomes a necessary tool to analyze these processes and the influence of operating conditions [5], [7]; matter transfer within the food is produced only by moisture gradients, which is known as a diffusive mechanism [8]. Thus, the modeling of the kinetics of drying allows obtaining parameters such as the effective diffusivity of the product, an essential parameter to approach the optimization of the drying process [9].

New pre-drying treatments are based on chemical manipulation that has reduced drying times [7], [10]; recently US has been applied in the hot air drying reducing processing time and energy consumption of the operation, by getting lower temperatures suitable for drying [11], [12]. It has also been shown to increase the rate of mass transfer during drying [7], [12], [13].

Nowadays, dried fruit snacks are taking great importance, as they possess specific properties such as crispness, natural fruit flavor, and high nutrient retention. Banana is one of the ideal candidates for drying and dehydration due to being a tropical fruit grown in many countries and being important to the economic sector. Banana (*Musa paradisiaca*) is an agricultural product with high sugar content, sweet taste, and nutritional value [14], [15].

Banana is one of the members of the Musaceae family and grows mainly in India, China, Uganda, Ecuador, Philippines, Nigeria, USA, and the European Union [16], [17]. This product contains the A, B, C, and E vitamins, different phenolic compounds including lignin, tannins, anthocyanins, catechin, and epicatechin [18] and various minerals, such as K, Ca, P, Na, Mg, Fe, Zn, and Mn [19]. Moreover, since this fruit consists of glucose, fructose, sucrose, and carbohydrates [20], it can be consumed as an appropriate source of energy. The negative point about banana is that it decays severely after-ripening and cultivation, which results in great agricultural wastes [21]. To overcome the high decaying rate of this product and to reduce its wastes, it can be dried after cultivation [22]. The drying process reduces the water activity of the sample to increase its shelf life [23] and decreases its volume to decline the packaging, storage, and transportation costs [16], [24].

Globally, it is reported that banana is the fourth most sought after food after rice, wheat, and corn [25]. According to the Ministry of Commerce, up to 2017, Colombia is the world's fifth-largest exporter of bananas. Banana is a perishable food product and is also sensitive to postharvest defects including bruising during transport, browning due to inappropriate ripening environments and it is reported that it may even be rejected due to "unacceptable" curved shape [26]. The purpose of this study was to evaluate the effect of sonication at 40KHz / 130W at 30 ° C for 10, 20, and 30 min on the kinetics of convective drying of banana (*Musa paradisiaca*).

Material and methods

Materials

Banana (*Musa paradisiaca*) in an optimum state of ripeness was chosen, that is, bananas with a uniform yellow color, in which the first black dots are just beginning to appear and in which the average total sugar content should be around 20%.

Preparation of raw material

The banana is peeled and placed on a tray, where it is subjected to a longitudinal slicing of 4 to 5 mm ± 1 thick, weighing approximately 3 to 4 g per sample.

Ultrasound treatment

A BRANSON 3800, Model M 3800H (40KHz) equipment was employed, and deionized water was used as the transmission medium, the samples (390g banana) to ultrasound frequency 40KHz / 130W at 30 ° C were subjected for 10, 20, and 30 minutes; the control sample were bananas without US treatment.

Convective drying

The determination of the kinetics of drying was performed in a convection dryer with small scale trays Model PS-SE-001 / PE, Brand Generators, the samples were placed in waxed paper to avoid overlapping and constant air velocity variables were controlled 0.2 m / s and 60 ° C; times were taken initially every five minutes until reaching ten, then weight and humidity data were taken every ten minutes until the weight was constant. The experiments were performed at least in triplicate and extended until the samples lost 22% of their initial weight [1].

Calculation of the effective diffusivity coefficient and activation energy

In the present experiment, the moisture ratio (MR) was used as independent variable Equation "(1)" which relates the moisture gradient of the sample in real time with the equilibrium moisture content [27]. To describe mathematically the kinetics of drying the integrated equation of Fick's second law was used for long periods "(2)" [28], [29].

$$MR = \frac{Xwt - Xwe}{Xwo} - Xwe \qquad (1)$$

$$MR = \frac{6}{\pi^2} \sum_{j=1}^{\infty} \frac{1}{j^2} exp\left[\frac{-j^2 D_{eff} \pi^2 t}{r^2}\right] \qquad (2)$$

Where: Xwt: moisture content in real time (kg w / kg m.s); Xwo: initial moisture content (w kg / kg m.s); Xwe: equilibrium moisture content (w kg / kg m.s); J: number of terms; T: time (min); R is the radius of the sample (m); Deff: effective water diffusivity (m^2 / s).

In general, the influence of the drying temperature on the coefficient of effective diffusivity of water in foods follows an Arrhenius type trend, the relationship described by equation "(3)" and by representing Deff vs 1 / T a straight line is obtained from whose slope the Ea is obtained and the Arrhenius factor (Do) is obtained from the intercept.

$$Deff = DO\exp\frac{Ea}{RT} \qquad (3)$$

Where: D0 is the Arrhenius factor, R is the universal gas constant and T is the absolute temperature.

Mathematical Modeling

Five thin layer mathematical models out of the most used in literature to represent the experimental drying kinetics were used. Table I shows the expression of selected models) [30], [15]: In these models, the dependent variable is MR which represents the moisture ratio (MR = M / M0). Where: M is the product moisture at a given time, moisture M0 at the initial time, t is the drying time, and k, n, a, b, c, g and h are parameters or constants in the models.

Table I. Mathematical models used by different authors in the study of drying behavior.

Equation	Nombre	Ecuación modelo	Referencias
"(4)"	Newton	$MR = \exp(-kt)$	[29]
"(5)"	Henderson and Pabi	$MR = a * \exp(-kt)$	[31]
"(6)"	Page	$MR = \exp(-ktn)$	[32]
"(7)"	Page Modificada	$MR = \exp(-kt)n$	[33]
"(8)"	Exponential	$MR = \exp(-k \cdot t)$	[15]

Fuente: Autor

Fitting of the model

In the modeling of the kinetics of drying, the effective diffusivity was identified by adjusting diffusive models to experimental data. The identification was carried out by the method of optimization of Generalized Reduced Gradient. (GRG), the fitting was determined from the percentage of explained variance (% VAR, "(9)") [3].

$$\%VAR = 1 - \frac{S_{xy}^2}{S_y^2} * 100 \qquad (9)$$

Where: Sxy and Sy are the standard deviation of the estimate and the sample, respectively.

To evaluate the fitting of the mathematical models with experimental data, the following statistical coefficients were used: the coefficient of determination (R2), CHI-square (X^2) "(10)"and squared sum of errors (SSE) "(11)". The best fittings were those models that had the lowest values of X^2 and SSE and the highest values of R^2 [34].

$$X^2 = \frac{\sum_{i=1} N(MR_{exp,i} - MR_{pre,i})^2}{N-z} \qquad (10)$$

$$SSE = \frac{1}{N} * \sum_{i=1} N \left(MR_{exp,i} - MR_{pre,i} \right)^2 \qquad (11)$$

where MRexp.i represents the moisture ratio obtained experimentally, MRpre.i are the predictions made by the mathematical models, N is the number of data z the number of constants. Fitting and calculations of these statistical analyzes were performed by using the Microsoft Excel 2010 software.

Statistical analysis

The results were treated statistically significant at a level of 95% (P <0.05), in order to discern the results of ANOVA better, the post hoc test of Minimum Significant Difference (DMS) SPSS statistical software package version 22.0 was used.

Results and discussion

Convective drying

Figure 1 shows the experimental curves of dried banana pretreated with US and the control sample, the

average initial moisture content of 4.57 ± 0.06 kg MS kg / W, which was regarded as the critical moisture content. In the initial stages of drying rapid removal of moisture from the fruit is observed and in later stages it decreases with an increase in the processing time, because the residual water is strongly adhered on the solid phase of the banana forming the monolayer [16], [35].

This behavior is typical in the drying of fruits and vegetables with or without US, as reported in various products such as cape gooseberry [29], [36], [37], yellow pitahaya [38], eggplant [39]. Treatments with the application of US showed significantly (p <0.05) higher moisture loss in a shorter processing time compared to the control treatment (no US); being 30 min treatment with US application the one which submitted the highest losses for the same drying time, followed by treatment with an application of 10 and 20 min of US that showed similar behavior (p> 0.05).
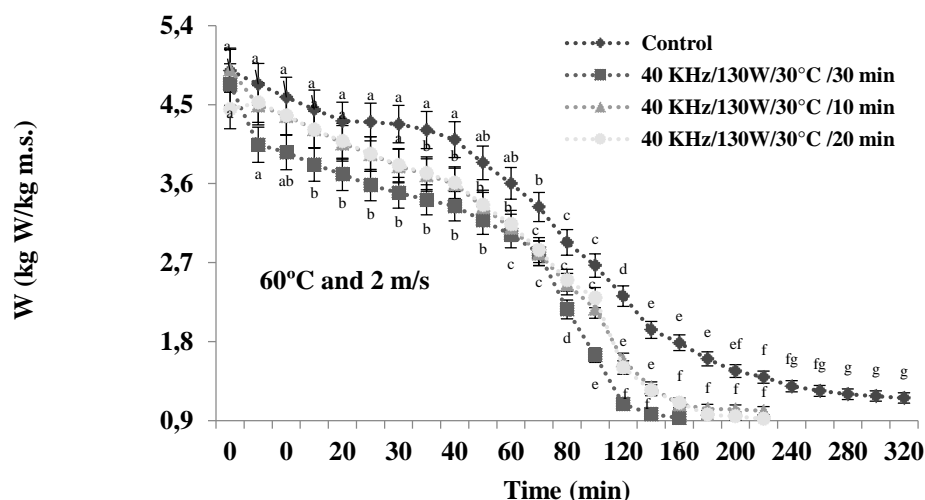

Figure 1. Curves of moisture content of banana pretreated with US (130W / 40kHz) during hot air drying (60 ° C and 2 m / s). ± SD: n: 3. The different letters represent statistical differences among the groups (p <0.05).

The samples treated with 30 min of US reached a humidity of 0.93 kg/kgm.s approximately at 160 min, whereas those treated at 10 and 20 min reached it at 220 min and the control sample at 320 min. According to these results the treatment of US for 30 min showed a reduction of drying time in 50%, and for 10 and 20 min in 31%.

The kinetics of drying of banana slices, where it was observed that at a convective drying temperature of 60°C/2 ms^{-1}; the samples without applying US needed 5h 20min to reach an average moisture content of 1.1 ± 0.1 kg water / gm.s. The US treatment increased significantly (p<0.05) the drying rate in all the samples treated with US at 40KH /130W/30°C compared to the control samples. As well, an average 50% reduction in the drying time was obtained by applying US; achieving a weight loss of 77% from the initial weight (40 to 9 g.).

This study on the effect of pretreatment with US in convective drying at 60°C and 2 ms-1 of banana (*Musa paradisiaca*), could establish that applying a frequency of 40KHz/ 130W/30°C for 30 min., increased the drying rate to almost half the time; probably due to the formation of microchannels due to systematic, alternate compression and decompression of the material (called "sponge effect") which facilitates the outflow of water from the matrix in the form of vapor by sublimation causing increased drying rates [1], [15], [16], [40].

Forming microchannels causes separation and disruption of the cells in response to the application of US without causing the disintegration of cells, as shown by research results in melons, papayas, and pineapples [41] – [43]. Bananas subjected to pretreatment with US in osmotic dehydration showed that the texture of the fruit was modified due to the dissolution of pectin and the distribution of cells after 30 min periods of pretreatment [42], [44], [45]. Moreover, this reduction is attributable to the mechanical energy generated in the US cavitation

process; causing a reduction in the internal and external resistance to the transfer of materials and the generation of microcurrents at the interfaces or the compressions and decompressions in the solid material, contributing to facilitating the exit of water from the matrix [15], [16].

The results are consistent with some authors who have evaluated the effect of US on drying of different fruits and vegetables such as in bananas, when using the US as a pretreatment in banana drying at 80 ° C with a speed of 3 m / s, drying time was reduced by up to 21.6% and energy consumption was reduced by 22% [16], a positive effect on the rate of convective drying at 70 ° C and 60W power was observed, achieving reductions of 35% [44] and of 50 % in immersion in a sucrose solution [45]. Wang et al. [46] obtained an increase in the weight loss of the okra or okra by exposing it to 25 kHz / 25 ° C for 15 minutes; in the grenade at 40 kHz / 100 W at 30 ° C for 60 and 80 min. the greatest loss of water was achieved [47]. Likewise, in potatoes, the drying time was reduced by 30% and 23% with US + ethanol and US + water respectively [48].

Rojas et al. [49]. immersed apple slices in ethanol for 30 min and convection-dried US ($21.77kHz/20.5kW$ m^3) ($50°C$, 1 m·s^{-1}), observing a reduction in conventional drying time of $70 \pm 2\%$. In pumpkin with convective drying of $50°C$ and 0.8 ± 0.1 ms - the combination of ethanol and US showed an increase in drying time (59%) and in energy consumption (44%) [50].

Determination of the diffusivity coefficient

The values of the effective diffusivity coefficient of water with and without the application of US are shown in Table II. The fitting of the model to the experimental values was better in the samples treated with US, with percentage values from 98.5 to 99.3 variance%, while the control it showed 87.3%.

Table II. Values of effective diffusion coefficient in the drying of banana with and without the application of ultrasound

Estimated parameters	Control	Treatments (40KHz/130W/30°C)		
		10 min	20 min	30 min
Deff(10^{-10} m^2/s)	3.04±0.97a	6.35±1.11b	7.13±1.2b	8.31±0.79c
%VAR	87.3	99.3	99.1	98.5

± SD: n: 3. The different letters (a, b) show statistical differences among the groups (p <0.05).

It is noted that the Deff value is significantly increased (p <0.05) with increasing exposure time to the US, from 6.63 to 8.33 x 10-10 m^2 / s; this may be due to the effect that the US causes by expanding the heating energy increases water diffusivity [3]. These values of Diffusivity are within the common range for most food and between 10 to 11 10-9m^2 / s [51]. It may be noted that treatments with US showed higher Deff value compared to control treatment, demonstrating the potential of US to accelerate water loss under drying conditions; this due to the formation of microchannels in the matrix of banana, facilitating the mobility of water molecules toward the outside. According to some researchers [44], this increasing in the diffusion coefficient with the application of US in the materials, causing an acceleration of the movement of inner water.

Similar results in Deff values were reported in previous studies of vegetables dried with pretreatment with US, such as strawberry [52], apple [3], potato [53], carrots [54], parsley leaves [55]. This effect is probably due to the variation of the expansions and contractions in the cycles produced by the power of the US in the material, a phenomenon that causes an acceleration in the movement of inner water, this being manifested in increased Deff values [44], [56].

Modeling of drying kinetics

Table III presents the estimated kinetic parameters using 5 models (Newton, Henderson and Pabis, Page, Page modified and exponential), including the quality criteria (R^2, SSE and x^2). The model that best represented

the experimental drying curves for the three conditions studied was the exponential model; R2closer to 1.0 and SSE and x^2 closer to zero.

The model that presents the best fit with the experimental data is the exponential one as shown in figure1; in previous studies of drying in banana [15], [16]; in onion [57]. and lemon [34] it has also been the best fit. Table 3 shows that the constant k is incremented in all kinetic models with the application time of US, which means that it is dependent on this time.

The k value is greater in treatments with US regarding the control sample, which could be associated indirectly to the loss of fruit water during drying. The ANOVA showed for all parameters of k in kinetic models, at a reliability level of 95%, significant differences ($p < 0.05$) in most cases, showing that the exposure time to US significantly affects the drying.

Table III. Values of the fitting parameters of the selected drying models

Models	Statistical tests	Control	Treatments (40KHz/130W/30°C)		
			US/10min	US/20min	US/30min
Newton	k (x10^{-3})	3.20±0.18[a]	6.10±0.19[b]	8.56±1.51[c]	12.02±1.24[d]
Henderson and Pabi	k(x10^{-3})	4.12±0.28[a]	6.76±0.35[b]	8.19±2.05 [b]	12.36±1.51[c]
Page	k(x10^{-4})	8.10±0.19[a]	9.12±1.55[a]	11.89±3.76[a]	25.96±8.54[b]
	n	1.25±0.01[a]	1.35±0.04 [b]	1.18±0.058[a]	1.35±0.054[b]
Page Modificada	k(x10^{-3})	2.91±0.11[a]	5.21±0.21[b]	8.23±0.46[c]	11.54±0.34[d]
	n	1.25±0.01[d]	1.30±0.01[b]	1.45±0.06[c]	1.32±0.05[c]
Exponencial	k(x10^{-2})	0.14±0.01[a]	0.35±0.02[b]	0.61±0.027[c]	1.01±0.05[d]
	n	1.56±0.04[a]	1.32±0.02[b]	1.31±0.026[b]	1.079±0.01[c]
	a	-0.51±0.06[a]	-0.21±0.04[b]	-0.14±0.02[c]	-0.03 ±0.01[d]

± SD: n: 3. The different letters (a, b) show statistical differences among the groups ($p < 0.05$).

Conclusion

The application of ultrasound (40 KHz / 130W / 30 ° C / 10, 20 and 30 min) as a pretreatment to the convective drying of banana samples showed a significant reduction of processing time when compared to the control sample; reaching the greatest reduction of time of 50% for the treatment subjected to 30 min of US. The model that best predicts banana drying kinetics with and without the application of US is the exponential one. According to these results the use of ultrasound would be a potential alternative to reduce the drying time of bananas and vegetables in general with significant saving of energy.

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