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Power Ultrasound Application on Convective Drying of Banana (*Musa paradisiaca*), Mango (*Mangifera indica* L.) and Guava (*Psidium guajava* L.)

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***Abstract*—**High moisture content in fruits generates post-harvest problems such as mechanical, biochemical, microbial and physical losses. Dehydration, which is based on the reduction of water activity of the fruit, is a common option for overcoming such losses. However, regular hot air drying could affect negatively the quality properties of the fruit due to the long residence time at high temperature. Power ultrasound (US) application during the convective drying has been used as a novel method able to enhance drying rate and, consequently, to decrease drying time. In the present study, a new approach was tested to evaluate the effect of US on the drying time, the final antioxidant activity (AA) and the total polyphenol content (TPC) of banana slices (BS), mango slices (MS) and guava slices (GS). There were also studied the drying kinetics with nine different models from which water effective diffusivities (Deff) (with or without shrinkage corrections) were calculated. Compared with the corresponding control tests, US assisted drying for fruit slices showed reductions in drying time between 16.23 and 30.19%, 11.34 and 32.73%, and 19.25 and 47.51% for the MS, BS and GS respectively. Considering shrinkage effects, Deff calculated values ranged from $1.67*10^{-10}$ to $3.18*10^{-10}$ m^2/s, $3.96*10^{-10}$ and $5.57*10^{-10}$ m^2/s and $4.61*10^{-10}$ to $8.16*10^{-10}$ m^2/s for the BS, MS and GS samples respectively. Reductions of TPC and AA (as DPPH) were observed compared with the original content in fresh fruit data in all kinds of drying assays.

***Keywords*—**Banana, drying, effective diffusivity, guava, mango, ultrasound.

I. Introduction

CONSUMER awareness of the fruit high with content of bio-active compounds as carotenoids, vitamins, minerals, dietary fiber and antioxidants has been driving the current remarkable global growth in the production and markets of fresh fruits and fruit products. Among this trend, tropical fruits have a great success due to the variety of flavors, colors, texture and nutritional properties. Mango (*Musa paradisiaca*), banana (*Mangifera indica* L.) and guava (*Psidium guajava* L.) are examples of the variety of tropical fruits that are commercialized in Colombia and exported abroad.

Mango is a tropical fruit that grows in template climates. India, China, Thailand, México and Brazil are the most important producing countries. Colombia is located in 20th place in the ranking of mango production, with 20% of the area occupied by the fruit corresponding to Tommy Atkins variety [1]. Banana is one of the most produced fruit in Colombia, it grows in the departments of Antioquia and Magdalena. Fresh banana represents 30% of the total exports. The production of guava in Colombia is 1280000 ton. growing mainly in the region of Santander [2]. The world market of the fresh guava is not significant compared with the total of exports (0.1%) [3]. However, the transport of fresh banana, mango and guava between producers and final markets causes fruits some problems like loss of nutritional and quality properties induced by ripening process of the fruit.

Dehydration is one of the oldest techniques of food preservation. Nevertheless, convective drying (the most used technique of dehydration) generally uses high temperatures triggering losses of flavors, color, texture, porosity, and nutrient content of dehydrated products. In order to overcome some of the mentioned drawbacks different techniques have been evaluated (i.e. ultrasound, microwave, infrared assisted drying, among others). The application of ultrasound (US) waves has been used mainly as pre-treatment through an immersion of the fresh fruit in a US water (or hypertonic aqueous solution) bath usually yielding lower drying times. Fernandes et al. reported, for pineapple, 11% of reduction time with ultrasound as pre-treatment before drying compared with the time required for conventional drying [4]. The US waves can also be applied by using air as transmitting medium or by direct contact of an US device on sample trays during drying. Gamboa-Santos et al. founded time reductions between 13 and 44% -depending of the power- using air as transmitting material [5], while Schössler et al. obtained time reductions of 27% using vibrating trays [6].

The aim of this work was to evaluate the drying kinetics of mango, banana, and guava slices during US assisted convective drying, and compare these results with those obtained from the conventional hot air drying. From the best corresponding fit thin layer drying model, there were estimated the effective diffusivity of water in dried layer for each dehydration test, with and without considering shrinkage of the samples. Antioxidant activity (AA) and total polyphenol content (TPC) of raw material and drying products were also measured and compared.

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II. Materials and Methods

A. Sample Preparation

Fresh mango, banana and guava were purchased from a local market in Manizales, Colombia. The fresh fruits were selected according the color, and apparent hardness. After cleaning and sanitization they were cut in slices (ca. 6.5 g, 0.006 m height and 0.040 m diameter)

B. Moisture Content

The initial moisture content of the fruits slices was determined using a moisture balance (MOC-120H, Shimadzu Corporation Japan) at 100°C.

C. Drying Operation Assisted by Ultrasound

Fruits slices were drying using a conventional drying chamber (Vigitemp, Thermolab, model TH58) adapted with a piezoelectric transducer (20 kHz, 45 W) in the dehydration holed plate. A high power ultrasound generator (Kavantic, model GEN-0433) regulated the acoustic signal (voltage, frequency and power). Air conditions (Relative humidity and air velocity) and temperature were measured using an anemometer (Extech Heavy Duty Hygro-Thermo-Anemometer).

D. Drying Operation

Fruit slices were put directly in the dryer on a holed plate at 50°C, 1± 0.2 m/s air velocity, 7±2% relative humidity. For each fruit three different types of drying tests were run: Without using US (Blank), 5 minutes, and 10 minutes of US interaction to the plate each half hour during the whole test. Sample slices were distributed closely around the piezoelectric device, ensuring the correct contact with the US vibrations. Weight evolution was recorded (every hour) until the desired final slice moisture content (10.0±1.0%) was reached. Each type of drying experiment was done in triplicate.

TABLE I
Drying Kinetics Models

Name model	*Model expression*	*Source*
Newton	$XR=exp(-kt)$	[7]
Henderson and Pabis	$XR=a\ exp(-kt^u)$	[8]
Midilli	$XR=a\ exp(-kt^u)+bt$	[9]
Wang and Singh	$XR=1+at+bt^2$	[10]
Logarithmic	$XR= a\ exp(-kt^u)+b$	[11]
Modified Page	$XR=exp(-[kt]^u)$	[12]
Page	$XR=exp(-kt^u)$	[13]
Verma et al.	$XR=a\ exp(-kt)+(1-a)exp(-bt)$	[14]
Two Term	$XR\ a\ exp(-k_ot)+b\ exp(-k_1t)$	[15]

E. Drying Kinetics Models

Nine thin-layer published models (Table I) were fitted to the dehydration evolution data using ORIGIN® Pro 8.1 software, in Table I:

$$XR = \frac{X-Xeq}{Xo-Xeq} \quad (1)$$

where *XR* is the adimensional moisture content (dry basis), *X*, *Xo* and *Xeq* are the moisture content in anytime, the initial moisture content and the equilibrium moisture content of the fruits respectively (dry basis). Statistical analysis was also established with ORIGIN® Pro 8.1 software, using R^2 and X_{2red} as criteria of the goodness-of-fit of the models.

F. Determination of Water Diffusivity

The values of water diffusivity were estimated according to Crank (2) analytical method [16] that is valid for the falling rate period (when internal moisture diffusion controls dehydration rate).

$$XR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-2(2n+1)^2\frac{\pi^2}{4}\frac{D_{eff}t}{L_0^2}\right) \quad (2)$$

where XR is the adimensional moisture content, *Lo,* initial thickness and D_{eff} is the diffusivity without shrinkage correction.

Equation (2) can be applied in two distinct time periods: at the beginning of the diffusion process (short diffusion period) and at the end of the diffusion process (long diffusion period). For this study shrinkage correction for sample thickness was considered and compared with the calculated diffusivity without shrinkage correction.

1. Estimation of Diffusivity for Short Diffusion Period

At the beginning of the diffusion period this drying period is comprised between the first and second critical moisture content The first critical moisture content represent the transition of the constant rate to the falling rate drying period [17], [18]. For short diffusion stage, (2) becomes:

$$\frac{\bar{X}}{X_{cri1}} = 1 - k\sqrt{\frac{t-t_{cri1}}{L^2}},\ k = \sqrt{\frac{4D_{eff1}}{\pi}} \quad (3)$$

where $\bar{X}$, is the moisture content,X_{cri1} is the first critical value, t_{cri1} is the time when the first critical value is reached.

2. Estimation of Diffusivity for the Long Diffusion Period

At the end of the diffusion period, this drying stage is comprised between the second critical and third critical moisture content points. For this period, (2) becomes:

$$ln\frac{\bar{X}}{X_{cri}} = \ln\frac{8}{\pi^2}exp\left[-\frac{\pi^2 D_{eff2}}{4}\frac{(t-t_{cri1})}{L^2}\right] \quad (4)$$

The water diffusivity can be calculated from the slope of the natural logarithm of moisture content and the ratio of the difference between the critical times, and the squared thickness.

In (3) and (4) *L=L(t)* considering shrinkage correction, otherwise L=*Lo.*

3. Shrinkage Estimation

For each fruit slices, shrinkage variation was measured during additional drying tests. Average diameter, thickness and weight evolution were recorded during dehydration until the samples reached 10.0% of final moisture content.

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G. Determination of Total Polyphenols Content and Antioxidant Activity

1. Ultrasonic Extraction

Each sample of dried mango, banana and guava (0,150 ± 0,001 g) were mixed with 1 mL of a solution of ethanol: hydrochloric acid: water (93:1:6 v/v) in a Eppendorf tube [19]. The tube was submerged during 2 hours in an US bath (Elma E30H, Singen, Germany) with 37 kHz and 240 W of power level. The temperature of the US bath was controlled between 23-25°C. Then, the acid ethanolic extract was centrifuged at 13500 rpm, during 20 minutes; the supernatant was collected and stored in an amber glass vial at 4°C, under dark condition until analysis.

2. Measurement of Total Polyphenols Content (TPC)

The total polyphenols content of the extract was measured by the Folin-Ciocalteu colorimetric method with modifications [20]. 150 µL of extract, was mixed with 2.4 mL of distilled water, 150 µL of Folin-Ciocalteu solution (1N) and 300 µL of sodium carbonate (20% w/v). After 2 hours reaction in the dark, absorbance was measured at a wavelength of 765 nm in a spectrophotometer (UV/ Visible-Model 6405, Jenway, Felsted, United Kingdom).

3. Determination of Antioxidant Activity by Inhibition the DPPH Radical

The DPPH assay was done according to the method described by [21]-[23], with modifications. For each sample, a series of dilutions were prepared, and the reaction was developed in spectrophotometer cuvettes containing 150 mL of extract solution and 3 mL of 60 mM DPPH ˙(Radical α, α-diphenyl-β- picrylhydrazyl dissolved in 96% ethanol, absorbance of 0.700 ± 0.001 to 517 nm). The solution was allowed to react during 1 hour (Dark conditions), then the absorbance was measured at 517 nm in a spectrophotometer. Pure ethanol was used as control. Radical inhibition was calculated according to (5).

$$Inhibition\ of\ absorbance\ \lambda_{517} = \left(1 - \frac{A_f}{A_o}\right) \times 100 \qquad (5)$$

where *Ao* is the absorbance of the control solution and A_f is the absorbance of the samples after 60 minutes of reaction. Percentage inhibition of the DPPH•1 radical was plotted as a function of antioxidant concentration, in order to obtain percentage inhibition of the DPPH in 50%.

III. Results

A. Effect of Ultrasound During Convective Drying

Initial moisture content of the samples were 82.01±0.7%, 73.17±0.1% and 86.66±1.0% for mango, banana and guava, respectively. Figs. 1-3 show the kinetics of drying operation for different US exposition times (0, 5 and 10 minutes, each half hour). Application of US by direct contact reduced significantly the operation time, finding shorter drying times when lower US exposition times was applied to mango and banana. In contrast, the guava fruit tests showed that larger US exposure times yielded shorter drying times. Table II shows the percentage reduction of drying times compared with the corresponding blanks. Garcia-Pérez et al. observed similar behavior for US application for drying of cassava at 40°C. They found drying time reductions of 32% using acoustic power of 21 W/m^3 [24].

TABLE II
Reduction of Drying Time (%)

	US exposure time	
Fruit	**5 min/half hr**	**10 min/half hr**
Mango	30.19%	16.23%
Banana	32.73%	11.34%
Guava	19.25%	47.51%

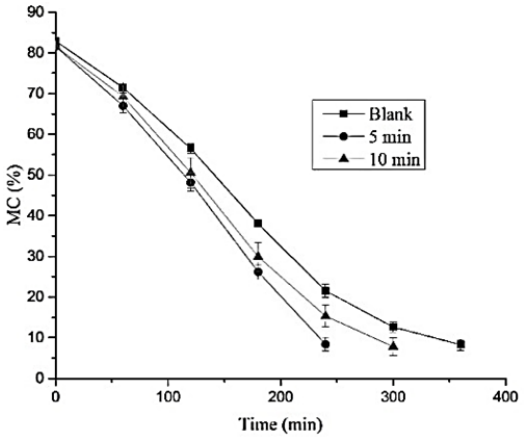


Fig. 1 Drying curves of mango at different US exposure time

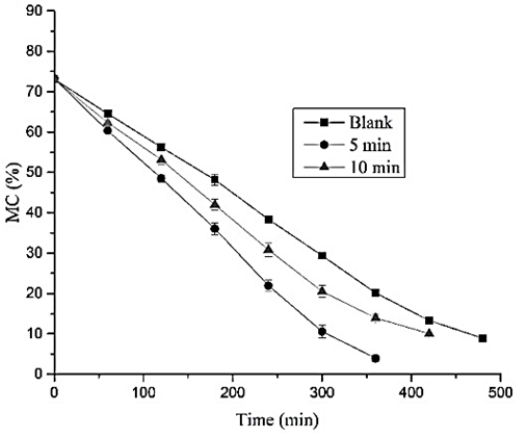


Fig. 2 Drying curves of banana at different US exposure time

The drying curves show a higher reduction time when mango and banana were exposed to US for 5 min/each half hr. However, the guava slices showed higher reduction when US time exposures was 10 min/each half hr. Reduction in drying time can be explained by the generation of microscopic channels in US treated samples that allow an easier water release during dehydration [24]. Differences between responses to the two levels of US exposition are attributed to structural differences of the fresh fruit materials.

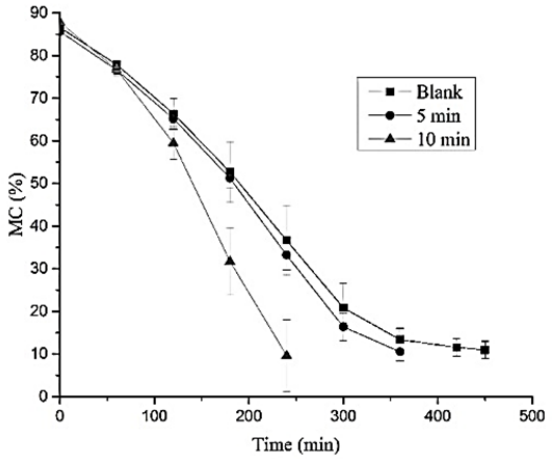


Fig. 3 Drying curves of guava at different US exposure time

B. Drying Kinetic Models

Data from the drying tests were fitted to the nine models presented in Table I. In Table III is shown the estimation of R^2 and X_{2red} of each model and type of mango drying test according to ORIGIN ® software.

TABLE III
STATISTICAL RESULTS FROM DRYING KINETICS CURVE OF MANGO AT 50°C

Model	R^2	X_2red
Blank		
Newton	0.9982	$2{,}30*10^{-4}$
Henderson and Pabis	0.9981	$2.68*10^{-4}$
Midilli	0.2584	0.09994
Wang and Singh	0.9124	0.00371
Logarithmic	0.9996	$4.71*10^{-5}$
Modified Page	0.9993	$8.99*10^{-5}$
Page	0.9993	$9.21*10^{-5}$
Verma	**0.9998**	$\mathbf{1.84*10^{-5}}$
Two-Term	0.9966	$4.47*10^{-4}$
5 min US exposure/each half hr		
Newton	0.9978	$2.92*10^{-4}$
Henderson and Pabis	0.9975	$3.40*10^{-4}$
Midilli	-0.04557	0.1438
Wang and Singh	0.00774	0.9437
Logarithmic	0.9981	$2.60*10^{-4}$
Modified Page	0.9999	$9.47*10^{-7}$
Page	**0.9999**	$\mathbf{9.41*10^{-7}}$
Verma	0.9980	$2.65*10^{-4}$
Two-Term	0.9986	$1.89*10^{-4}$
10 min US exposure/each half hr		
Newton	0.99929	$9.28*10^{-5}$
Henderson and Pabis	0.99914	$1.11*10^{-4}$
Midilli	0.27426	0.0943
Wang and Singh	0.96930	0.00481
Logarithmic	0.99946	$7*10^{-5}$
Modified Page	0.99915	$1.10*10^{-4}$
Page	0.99914	$1.11*10^{-4}$
Verma	**0.99969**	$\mathbf{4.06*10^{-4}}$
Two-Term	0.9985	$1.85*10^{-4}$

Although most of the models fit well (values of R^2 and X_{2red} close to 1 and 0, respectively), Verma model showed the best statistical parameters for the blank and the 10 min US exposure tests while Page model displays the best fit for the 5 minutes US exposure drying.

By using the same criteria in Table IV is summarized the best fit models for each fruit drying run. It is important to note that all models describe acceptably the drying behavior with the exceptions of the Midilli and the two term models.

TABLE IV
BEST-FIT MODELS IN DRYING ASSAYS

	US exposure time		
Fruit	**0 (Blank)**	**5 min/half hr**	**10 min/half hr**
Mango	Verma	Page	Verma
Banana	Verma	Logarithmic	Verma
Guava	Verma	Logarithmic	Logarithmic

C. Effect of Ultrasound on Water Diffusivity

In order to find the differences between the drying rate periods, Fig. 4 shows the drying rate as function of the water content in dry basis and the comparison between a drying rate with and without shrinkage correction. The line that represent the drying rate without shrinkages correction, only shows the falling rate period, while the line of the drying rate with shrinkage correction shows the heating up, constant rate and falling rate periods. This former line was used for the determination of the first, second and third critical value from (3) and (4). This procedure was also applied to mango, banana and guava drying for the blank, 5 and 10 minutes US exposure tests.

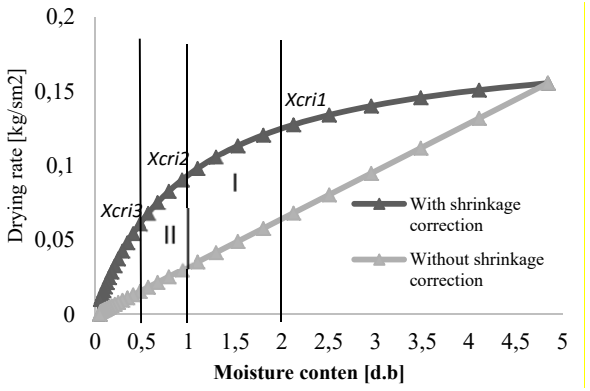


Fig. 4 Drying rate for mango slices without US or blank

D. Moisture Diffusivity Estimation between the First, Second, and Third Critical Value

The moisture diffusivity was determined according (3) and (4) considering both the change of L (thickness) in the time and keeping it constant. As expected, the values of moisture diffusivity increased with temperature and time of exposure to ultrasound. The Table V shows the values of water diffusivity in the region I and II, taking into account or not the shrinkage effect for mango, banana and guava slices.

Mango and banana slices, showed higher diffusivity values for the assays with 5 minutes of US exposure. Furthermore, guava slices, presented higher values with 10 minutes

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exposure. These results confirm the effect of US on the drying rate.

According to the results from Table V, for both regions, the ratio between the effective diffusivities with and without shrinkage correction was approximately 10 (from 10^{-9} to 10^{-10}).

TABLE V
MOISTURE DIFFUSIVITY FOR FRUIT SLICES

Drying condition	Region I Lo (m)	Region I L(t) (m)	Region II Lo (m)	Region II L(t) (m)
Water diffusivity for mango slices, Deff (m2/s)				
Blank	1.55×10^{-9}	$3{,}96 \times 10^{-10}$	1.78×10^{-9}	2.28×10^{-10}
5 min	2.47×10^{-9}	$5{,}56 \times 10^{-10}$	3.09×10^{-9}	3.87×10^{-10}
10 min	1.65×10^{-9}	$4{,}11 \times 10^{-10}$	2.27×10^{-9}	3.13×10^{-10}
Water diffusivity for banana slices, Deff (m2/s)				
Blank	8.18×10^{-12}	1.67×10^{-10}	7.54×10^{-12}	1.26×10^{-10}
5 min	1.3×10^{-9}	3.18×10^{-10}	7.94×10^{-10}	1.69×10^{-10}
10 min	6.95×10^{-10}	1.84×10^{-10}	5.48×10^{-10}	1.56×10^{-10}
Water diffusivity for guava slices, Deff (m2/s)				
Blank	1.38×10^{-9}	4.60×10^{-10}	1.92×10^{-9}	3.70×10^{-10}
5 min	2.45×10^{-9}	6.05×10^{-10}	3.08×10^{-9}	4.06×10^{-10}
10 min	3.38×10^{-9}	8.16×10^{-10}	4.43×10^{-9}	4.61×10^{-10}

Dissa et al. found values for water diffusivity in mango drying from 1.66×10^{-10} to 1.28×10^{-9} m^2/s [17]. Nguyen reported 3.1×10^{-10} m^2/s for this property in banana dehydration at 50°C [25]. Finally, for guava the water diffusivity ranged from 5.139×10^{-10} to 7.624×10^{-10} m^2/s according to [26].

E. Effect of Ultrasound on Total Polyphenols Content (TPC) and Antioxidant Activity

The total polyphenols content (TPC) of fresh mango, banana and guava were 443.29, 330.58 and 3059.05 mg GAE/ g dry fruit, respectively. Alothman et al. found similar results: 268.4 and 708.21 mg GAE/ g dry fruit for fresh banana and guava, respectively [27]. For mango, the value found by Siddiq was 400.23 mg GAE/ g dry fruit [28].

In the present work the hot air and the US application caused a reduction in TPC content in dried fruits. This effect could be explained by the release of oxidative enzymes and intra-cellular compounds owing to sample mechanical stress linked to US exposition [29].

Antioxidant activities (AA) determined by DPPH method were 5754.75, 4315.57 and 16957.94 µM Trolox/ g dry fruit for fresh mango, banana and guava slices, respectively. For this measurement, there were also observed DPPH reductions in dried fruit compared to those of the fresh fruit, showing lower values for the assays of 5 minutes US exposure for mango and banana slices, and 10 minutes US exposure tests for guava slices. The general results from reductions in TPC and AA are shown in Fig. 5.

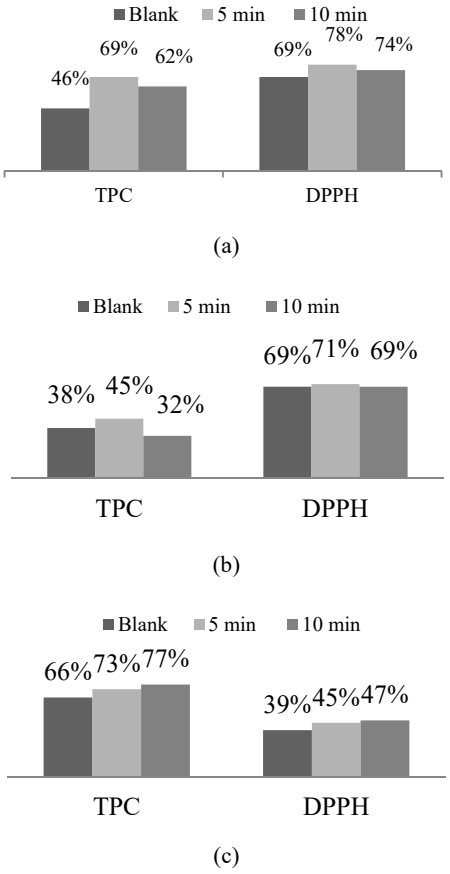


Fig. 5 Reduction percentage of total polyphenol content and antioxidant activity after drying of (a) Mango, (b) banana, (c) guava slices

IV. CONCLUSIONS

Overall, the results showed the positive effect of ultrasound application on the drying time in convective drying of mango, banana and guava slices. These results were confirmed by the upper values of water diffusivity estimations for US treated samples. However, for the fruits and the two levels of US exposition used in this study, the polyphenol content and the antioxidant activity showed reductions in comparison with the obtained with conventional convective drying.

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REFERENCES

[1] FAO, "The market for organic and fair-trade mangoes and pinneapples," no. September, pp. 4–9, 2009.
[2] D. C. Restrepo-Sánchez, C. E. Narváez-Cuenca, and L. P. Restrepo-Sánchez, "ExtracciÓN de compuestos con actividad antioxidante de

Open Science Index, Biotechnology and Bioengineering Vol:9, No:10, 2015 publications.waset.org/10002639/pdf

frutos de guayaba cultivada en vélez-santander, Colombia," *Quim. Nova*, vol. 32, no. 6, pp. 1517–1522, 2009.
[3] "Guayaba, variables internacionales," *Manual del exportador de frutas, hortalizas y tubérculos en Colombia*, 2000. (Online). Available: http://interletras.com/manualcci/Frutas/Guayaba/guayaba02.htm. (Accessed: 23-Aug-2015).
[4] F. a N. Fernandes, F. E. Linhares, and S. Rodrigues, "Ultrasound as pre-treatment for drying of pineapple," *Ultrason. Sonochem.*, vol. 15, no. 6, pp. 1049–1054, 2008.
[5] J. Gamboa-Santos, A. Montilla, J. A. Cárcel, M. Villamiel, and J. V. Garcia-Perez, "Air-borne ultrasound application in the convective drying of strawberry," *J. Food Eng.*, vol. 128, pp. 132–139, 2014.
[6] K. Schössler, H. Jäger, and D. Knorr, "Effect of continuous and intermittent ultrasound on drying time and effective diffusivity during convective drying of apple and red bell pepper," *J. Food Eng.*, vol. 108, no. 1, pp. 103–110, 2012.
[7] A. S. Mujumdar, *Handbook of industrial drying*. CRC Press, 2014.
[8] Q. Zhang and J. B. Litchfield, "An optimization of intermittent corn drying in a laboratory scale thin layer dryer," *Dry. Technol.*, vol. 9, no. 2, pp. 383–395, 1991.
[9] A. Midilli, H. Kucuk, and Z. Yapar, "A new model for single-layer drying," *Dry. Technol.*, vol. 20, no. 7, pp. 1503–1513, 2002.
[10] C. Y. Wang and R. P. Singh, "A single layer drying equation for rough rice," *ASAE Pap.*, vol. 78, p. 3001, 1978.
[11] A. Yagcioglu, A. Degirmencioglu, and F. Cagatay, "Drying characteristic of laurel leaves under different conditions," in *Proceedings of the 7th international congress on agricultural mechanization and energy*, 1999, vol. 26, no. 27, pp. 565–569.
[12] G. M. White, T. C. Bridges, O. J. Loewer, and I. J. Ross, "Seed coat damage in thin layer drying of soybeans as affected by drying conditions," *American Society of Agricultural Engineers, paper no. 3052*. 1978.
[13] L. M. Diamante and P. A. Munro, "Mathematical modelling of hot air drying of sweet potato slices," *Int. J. food Sci. Technol.*, vol. 26, no. 1, pp. 99–109, 1991.
[14] L. R. Verma, R. A. Bucklin, J. B. Endan, and F. T. Wratten, "Effects of drying air parameters on rice drying models," *Trans. ASAE-American Soc. Agric. Eng.*, 1985.
[15] S. M. Henderson, "Progress in developing the thin layer drying equation (for maize)," *Trans. ASAE*, 1974.
[16] J. Crank, *The mathematics of diffusion*, Second. Oxford university press, 1979.
[17] A. O. Dissa, H. Desmorieux, F. Ouattara, P. Degraeve, D. J. Bathiebo, and J. Koulidiati, "Influence of fruit maturity on water diffusivity during convective drying of mango," *Phys. Chem. News*, vol. 60, no. July, pp. 122–132, 2011.
[18] L. Hassini, S. Azzouz, R. Peczalski, and a. Belghith, "Estimation of potato moisture diffusivity from convective drying kinetics with correction for shrinkage," *J. Food Eng.*, vol. 79, no. 1, pp. 47–56, 2007.
[19] C. L. Taylor, "Purple Pepper Plants, An Anthocyanin Powerhouse: Extraction, Separation and Characterization," University of Maryland, 2014.
[20] V. L. Singleton, R. Orthofer, and R. M. Lamuela-Raventos, "Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent.," *Methods Enzymol.*, no. 299C, pp. 152–178, 1999.
[21] G. Marinova and V. Batchvarov, "Evaluation of the methods for determination of the free radical scavenging activity by DPPH," *Bulg. J. Agric. Sci.*, vol. 17, no. 1, pp. 11–24, 2011.
[22] P. Molyneux, "The use of the stable free radical diphenylpicrylhydrazyl (DPPH) for estimating antioxidant activity," *Songklanakarin J Sci Technol*, vol. 26, no. 2, pp. 211–219, 2004.
[23] W. Brand-Williams, M. E. Cuvelier, and C. Berset, "Use of a free radical method to evaluate antioxidant activity," *LWT-Food Sci. Technol.*, vol. 28, no. 1, pp. 25–30, 1995.
[24] C. Ozuna, T. G. Álvarez-arenas, E. Riera, J. A. Cárcel, and J. V Garcia-perez, "Ultrasonics Sonochemistry Influence of material structure on air-borne ultrasonic application in drying," *Ultrason. - Sonochemistry*, vol. 21, no. 3, pp. 1235–1243, 2014.
[25] M. H. Nguyen and W. E. Price, "Air-drying of banana: Influence of experimental parameters, slab thickness, banana maturity and harvesting season," *J. Food Eng.*, vol. 79, no. 1, pp. 200–207, 2007.
[26] S. P. Kek, N. L. Chin, and Y. A. Yusof, "Simultaneous time-temperature-thickness superposition theoretical and statistical modelling of convective drying of guava," *J. Food Sci. Technol.*, vol. 51, no. December, pp. 1–14, 2013.
[27] M. Alothman, R. Bhat, and a. a. Karim, "UV radiation-induced changes of antioxidant capacity of fresh-cut tropical fruits," *Innov. Food Sci. Emerg. Technol.*, vol. 10, no. 4, pp. 512–516, 2009.
[28] M. Siddiq, D. S. Sogi, and K. D. Dolan, "Antioxidant properties, total phenolics, and quality of fresh-cut 'Tommy Atkins' mangoes as affected by different pre-treatments," *LWT - Food Sci. Technol.*, vol. 53, no. 1, pp. 156–162, 2013.
[29] J. V. Santacatalina, O. Rodríguez, S. Simal, J. a. Cárcel, a. Mulet, and J. V. García-Pérez, "Ultrasonically enhanced low-temperature drying of apple: Influence on drying kinetics and antioxidant potential," *J. Food Eng.*, vol. 138, pp. 35–44, 2014.

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