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Effect of convective drying assisted by ultrasound on drying time and aroma of tamarillo (*Cyphomandra betacea* Cav. *Sendt)* and mango (*Mangifera indica* L.) fruits

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Abstract

New trends in global healthy food consumption have increase the production of fresh fruits and fruit based value-added products as a result of the awareness of their high contents of bio-active compounds like carotenoids, vitamins, minerals, dietary fiber and antioxidants. High moisture content in fruits can generate high losses in post-harvest handing, storage and distribution. Dehydration process based on water activity reduction, is a common option for overcoming such losses. 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 new method able to decrease drying time. The aim of this work was to evaluate the effect of the convective drying assisted by ultrasound on drying time and aroma losses of tamarillo slices (TS) and mango slices (MS). An experimental design was developed for both fruits, showing the positive effect of ultrasound during convective drying process. Power ultrasound (20 kHz, 45 W) was applied in different cycles during drying test at 50°C, applying 5 minutes and 10 minutes of ultrasound each half hour intermittently. Weigh loss of samples was measured every hour until reaching moisture content of 10.0±1.0% (wet basis). Aroma losses measurement was development by SPME method, and the results were compared with the fresh fruit data for all the drying tests.

Keywords: Aroma, convective drying, mango, tamarillo, ultrasound

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1 Introduction

In recent years, FAO has reported that fruit losses in developing countries represents between 40% and 50% of total production, caused by financial, administrative and technical limitations in different steps supply chain steps, leading to negative environmental impact [1]. Convective drying is one of the most used preservation techniques for fruits, due to the low operational costs and simple technology. This process reduces weight and volume in final products decreasing transportation and storage costs [2]. Drying requires temperatures higher than 60°C and prolonged exposure times increasing energy costs and compounds degradation like vitamins, polyphenols, essential oils, polysaccharides and antioxidants, affecting nutritional and organoleptic properties [3].

An alternative to reduce drying time and consequently to maintain the sensorial and nutritional properties of the product is ultrasound (US) application during- or as a pretreatment- convective drying [4]. US is defined as sound waves with frequencies higher than 20 KHz, which causes rapid compression and expansion intervals when travels through of the material (sponge effect), generating micro-channels that increase water diffusion during convective drying and therefore decrease time and/or temperature of operation avoiding degradation of nutritional content and sensorial quality [5].

Most of the US assisted fruit drying research use the US as pretreatment. This is usually made by the immersion of the fruit in an US bath, using water or an aqueous hypertonic solution as the transport media, at certain temperature, during an established exposure time. After the immersion the sample is taken out of the bath, rinsed and placed in the preheated tray dryer. Fernandes and Rodrigues (2007) reported reduction time up to 11% and increase in effective diffusivity of 14% when 20 kHz US pretreatment for banana drying was applied [6]. Other alternative is the application of US directly during drying using oscillating piezoelectrics coupled to trays of dryer [7].

Water vapor diffusivity is used as a parameter to compare different drying processes because gives an idea of water velocity released from solid matrix to air. Since this transport coefficients cannot be measured directly, adequate mathematical models including this parameter have been developed. The effective diffusion coefficient can be estimated by fitting these models to the dehydration experimental data [8].

Aroma of fruits consists in a mixture of a large number of volatile compounds such as aldehides, alcohols, ketones, esters, lactons, terpens, etc., which can be produced during cultivation, ripening, harvest, post-harvest and storage through different metabolic pathways, often, intentionally to improve organoleptic properties of the product [9]. Composition of volatile compounds for each fruit is diverse, specific and represent only 0.01% to 0.1% of total weight of fresh fruit, and is an important sensorial parameter affecting commercial value of product [10]. When drying is applied to increase shelf-life of fruits, aroma is one of the most affected characteristics in the process since some volatile compounds are lost and others undesirable are generated [11].

Tamarillo (*Cyphomandra betacea* Cav. *Sendt*) is a native fruit from South America, cultivated in cold climates, between 1.500 and 2.000 meters of altitude. It is a very attractive fruit for consumers by its organoleptic and nutritional properties, since has higher contents of iron and vitamins[12]. It is considered a promising crop in Colombia [13]. Methyl Hexanoate, (E)-hex-2-enal, (Z)-hex-3-en-1-ol, eugenol and 4-allyl-2,6-dimethoxyphenol are major constituents of tamarillo aroma [14].

Mango (*Mangifera indica L.*) is a tropical crop that grows in template climates. It is an important source of energy, dietary fiber, carbohydrates, proteins, fats, phenolic compounds, carotenoids and vitamin C and helps to prevent cardiovascular diseases and cancer [15]. Mango occupies the second worldwide position as a tropical crop, in terms of production and acreage [16]. Its aroma mainly consists in a mixture of terpenes, especially δ-3-carene [17,18].

In this study, the objective was to evaluate the effect of ultrasound (US) application on convective air drying of tamarillo and mango slices on drying time and aroma losses.

2 Materials and methods

2.1 Sample preparation

Fresh mango and tamarillo 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)

2.2 Moisture content

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

2.3 US assisted drying

Fruits slices were drying using a conventional drying chamber (Vigitemp, Thermolab, model TH58, Itagui, Colombia) adapted with a piezoelectric transducer in the dehydration holed plate. The transducer was connected to a high power US generator (Kavantic, model GEN-0433, Medellín, Colombia) with 20 kHz, 45 W). Air conditions (Relative humidity and air velocity) and temperature were measured using an anemometer (Extech Heavy Duty Hygro-Themo-Anemometer, New Hampshire, USA).

2.4 Drying operation

Fruit slices were put directly in the dryer on a holed plate at 50°C, 1.0± 0.2 m/s air velocity, and 7.0±2.0% relative humidity. Three different types of drying tests were run for each fruit: without using US (Blank), 5 minutes, and 10 minutes of US application on 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 by triplicate.

2.5 Determination of effective diffusivity (*Deff*)

The effective diffusivity (*Deff*) was estimated using the second law of Fick that considered the steady-state diffusion [8]. The slope method for uniform moisture distribution and negligible external resistance was applied following equation [9]:

$$M_R = \frac{M - M_e}{M_o - M_e} = \frac{8}{\pi^2}\exp\left(-\frac{D_{eff}\,\pi^2}{L^2}t\right) \quad (Eq.1)$$

M_R, M, Me and Mo, the non-dimensional, and the moisture content at time t [s]; the equilibrium, and the initial moisture content of the sample (dry basis). L [m], the sample thickness and *Deff* [m^2/s] the effective diffusivity. This slope method can only estimate the initial effective water diffusivity since the shrinkage effect is not considered [10]

2.6 Drying Kinetic Models

Three thin layer models were also fitted to the experimental drying evolution data using ORIGIN PRO 8.1 software.

Statistical analysis was established using R^2 and X_{2red} as a criteria to goodness-of-fit of the models. Table dE1 shows the three fitted model equations.

Table 1. Drying kinetic models

Name model	*Model expression*	*Source*
Newton	$M_R=exp(-kt)$	[19]
Henderson and Pabis	$M_R=a\ exp(-kt^u)$	[20]
Page	$M_R=exp(-kt^u)$	[21]

2.7 Volatile analysis by Headspace – Solid Phase Micro Extraction (HS-SPME)

Volatile analysis for tamarillo and mango were performed on samples of the fresh fruit and the dried fruit from the assay that showed the highest reduction in drying time.

The volatile compounds released from the headspace of fresh and dried tamarillo and mango slices were analyzed by HS-SPME [22] using a Divinylbenzene/Carboxen/Polydimethylsiloxane

(DVB/CAR/PDMS) fiber with a 50/30 µm thickness coating, combined with gas chromatography/ mass spectrometry. The fiber and manual SPME holder were purchased from Supelco (Bellefonte, Pa., U.S.A.). HS-SPME sampling was done in triplicate. 1g of fresh fruit pulp and dried fruit were separately mixed with 1 mL of distilled water, and then equilibrated for 1 h in a 4-mL screw-top vial with PTFE silicone septa at 60 °C using a magnetic stirrer [23]. The headspace was collected on a DVB/CAR/PDMS fiber (50/30 µm thickness) during 1 h, and then injected directly (desorption time was set at 10 min) into a gas chromatograph. In all cases fibers were conditioned previously following manufacturer instructions, and reconditioned before each sampling.

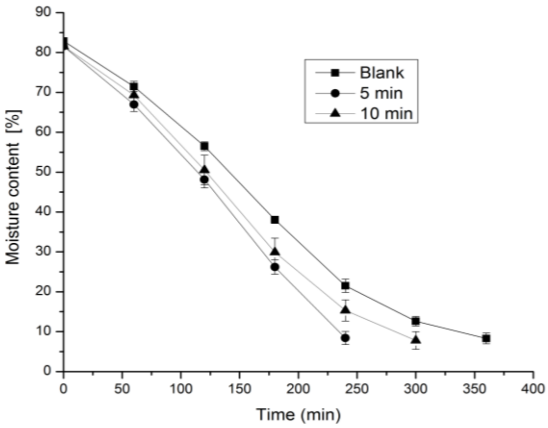
2.8 GC-MS analysis

The spectroscopic and chromatographic data were obtained with a gas chromatograph GC 6850 Series II (Agilent Technologies, Palo Alto, CA, USA) equipped with a mass selective detector MSD 5975B inert MSD (electron impact ionization, EI, 70 eV; Agilent Technologies), operated in splitless mode, and an MS-ChemStation G1701-DA data system, which included the spectral libraries WILEY and NIST. A fused-silica capillary column HP-INNOwax column coated with poly(ethyleneglycol) (J&W Scientific 30 m × 0.25 mm i.d. 0.25 µm film thickness) was used. With the HP-INNOwax column, the oven temperature was programmed from 40°C (1 min) to 180°C at 4°C/min, then to 250°C (6 min) at 12°C/min. The temperatures of the injection port, ionization chamber, and transfer line were set at 250, 230, and 280°C, respectively. Helium 5.0 (99.999%, Praxair, Bogotá, Colombia) was used as carrier gas, with 112 kPa column head pressure and 51 cm/s linear velocity (2 mL/min, at constant flow). Mass spectra (MS) and reconstructed total ion chromatograms were obtained by automatic scanning in the mass range *m/z* 45-350. Chromatographic peaks were checked for homogeneity with the aid of the mass chromatograms for the characteristic fragment ions and with the help of the peak purity function of the MS-Chemstation G1701-DA software. Linear retention indices were calculated according to the Kovàts method using a mixture of normal paraffin C_8–C_{20} as external references. Compound identification was based on chromatographic (retention times and indices) and spectroscopic (MS interpretation, comparison with databases) criteria [24–28].

3 Results and discussion

3.1 Effect of US on convective drying

Initial moisture content in fresh mango and tamarillo were 82.01±0.7% and 87.55±1.8% respectively, and the final moisture content was 10.0±1.0% in both cases.



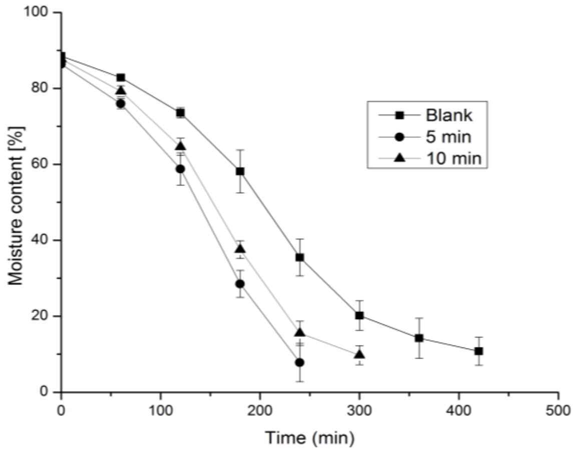


Figure 1. Drying curves of a) Mango slices b) Tamarillo slices

Figure 1 shows the moisture progress in drying assays for mango and tamarillo slices. For both fruits, US application during 5 minutes each half hour, intermittently, at 50°C, presented the highest reduction in drying time. Table 2 shows the percentage reduction of drying time compared with the corresponding blank. Kowalski *et al.* (2016) showed reductions in drying time of 79% for raspberries [29]. Garcia-Pérez *et al.* (2014) , also showed drying time reductions of 32% using acoustic power on cassava samples [30].

Figure 2 shows the estimations of effective water diffusivity (Deff). As expected, the highest values of this parameter for both fruit drying assays were found for the same US treatment (5 minutes/each half hour). For tamarillo slices the growth of Deff were 75% and 36% for the two US studied treatments compared with the estimated parameter for the blank test. Lower rise were assessed for mango slices (22.4% and 5.6% for 5 min and 10 min of US application each half hour, respectively).

The major sponge effect and the increase of microscopic channels in the fruit matrices was confirmed for the 5 min/half hour of US exposition; ulterior exposition to US apparently led to the partial collapse of this US micro-structure modification for the studied fruits.

Table 2. Reductions in drying time respecting the blanks

	US exposure time	
Fruit	**5 min/half hr**	**10 min/half hr**
Mango	30.19±1.69%	16.23±1.57%
Tamarillo	45.59±1.98%	39.53±2.02%

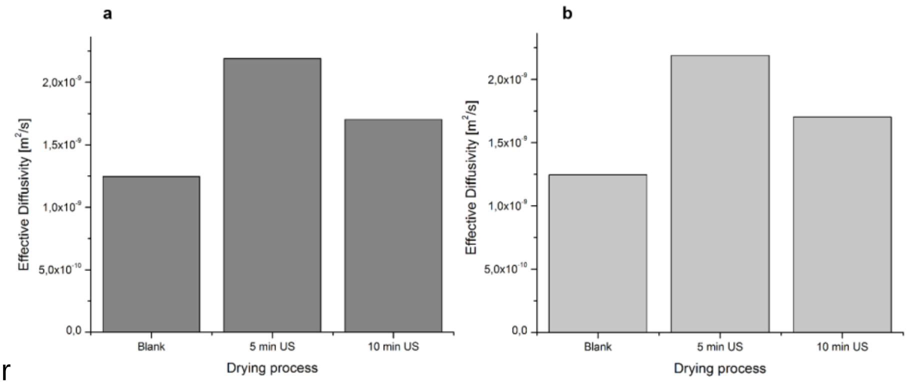


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Figure 2. Effective water diffusivity for a) Mango and b) Tamarillo slices in US air drying

3.2 Drying Kinetic

Three models were analysed to estimate the drying kinetic (Table 1). Table 3 presents the fitting results from each model on both fruits evaluated. For mango slices, the Page model was the best fitted for the operation without US and 5 min and 10 min each half hour US exposition. Page was also the best-fitted model for tamarillo slices. Although the three models describe an acceptable drying behaviour, Page model showed the best fit for the blank, 5 and 10 minutes of US application in both fruit drying.

Table 3. Mango and tamarillo drying kinetics curve

	Newton $MR = \exp(-kt)$		Page $MR = \exp(-kt^n)$		Henderson and Pabis $MR = aexp(-kt)$	
Model	R^2	X_2red	R^2	X_2red	R^2	X_2red
			Mango			
Blank	0.9983	$2.31*10^{-4}$	**0.9993**	**$9.21*10^{-5}$**	0.9980	$2.69*10^{-4}$
5 min US*	0.9978	$2.92*10^{-4}$	**0.9999**	**$9.42*10^{-7}$**	0.9975	$3.40*10^{-4}$
10 min US*	**0.9992**	**$9.29*10^{-5}$**	0.9991	$1.11*10^{-4}$	0.9991	$1.13*10^{-4}$
			Tamarillo			
Blank	0.9920	0.00104	**0.9992**	**$1.08*10^{-4}$**	0.9915	$1.11*10^{-3}$
5 min US*	0.9932	0.00113	**0.9980**	**$3.27*10^{-4}$**	0.9912	$1.47*10^{-3}$
10 min US*	0.9919	0.00123	**0.9985**	**$2.21*10^{-4}$**	0.9903	$1.47*10^{-3}$

*: Each half hour during drying process.

3.3 Aroma analysis

Aroma profiles were determined for samples obtained from the US treatment with the highest time reduction. They were compared with fresh fruit aroma profiles to evaluate losses on volatile compounds during these treatments.

Fresh mango analysis showed that δ-3-Carene, β-Elemene, β-Caryophyllene and Humulene were the most representative compounds of aroma profile. After drying process, the latter three compounds were not detected in the dried fruit. These volatiles were degraded, reduced or missed by the temperature exposure during drying. In contrast, *δ*-3-Carene, remained or even increased its relative abundance in dehydrated mango. According GC-MS analysis, other compounds that contributed to the mango aroma were the α-pinene, β-myrcene, δ-3-Carene, p-cymene, D-Limonene and α-Terpinolene, which were also previously reported [31]. They also remained or increased their relative abundance in dried samples.

On the other hand, Tamarillo aroma analysis, showed that the most important compounds in fresh fruit aroma were Ethyl butanoate, Methyl hexanoate, Eucalyptol, and Ethyl hexanoate, being Methyl hexanoate the compound with highest relative abundance. In dried tamarillo, all of them remained, but the relative abundance of Ethyl hexanoate was increased.

4 Conclusions

Here we report the effect of ultrasound (US) application on convective air drying of tamarillo and mango slices on drying time and aroma losses.

For both fruits, the highest drying time reduction were found when 5 minutes/half hour of ultrasound (US) was applied intermittently. Tamarillo US assisted drying showed higher reduction times than mango. The increase in the effective diffusivity for these conditions validated this result.

Tamarillo aroma profile was not greatly affected by US treatment studied conditions, since, their most representative volatile compounds remained in dried fruit. In contrast, mango volatiles were altered during examined drying conditions. However, *δ*-3-Carene, which is the most representative compound, it was not affected by the application of US assisted convective drying. Studies on olfactometry and sensory analysis need to be addressed in future research, for better understanding of the relationships of flavor/aroma phenomena and US assisted fruit drying.

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