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Direct and indirect power ultrasound assisted pre-osmotic treatments in convective drying of guava slices

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ABSTRACT

Application of ultrasound to osmotic dehydration of guava slices via indirect sonication using an ultrasonic bath system and direct sonication using an ultrasonic probe system was studied. Pre-treatments were designed in three osmotic solution concentrations of 0, 35, and 70 °Brix at indirect ultrasonic bath power from 0 to 2.5 kW for immersion times ranging for 20–60 min and direct ultrasonic probe amplitudes from 0 to 35% for immersion times of 6–20 min. The calculated ultrasound intensities from calorimetric ultrasound power dissipated indicated that direct sonication was more intensive than indirect sonication. The general linear model (GLM) showed that ultrasound input (power and amplitude), osmotic solution concentrations, and immersion time increased the water loss, solid gain, and total colour change of guava slices significantly with $P < 0.0005$. Indirect sonication in osmotic solutions contributed to high water loss and solid gain with acceptable total colour change than direct sonication. Applying ultrasound pre-osmotic treatment in 70 °Brix prior to hot-air drying reduced the drying time by 33%, increased the effective diffusivity by 35%, and decreased the total colour change by 38%. A remarkable decrease of hardness to 4.2 N obtained was also comparable to the fresh guava at 4.8 N.

Keywords: Guava; Drying; Ultrasound pre-treatment; Fruit quality

1. Introduction

Dehydration, or drying, is the most common and effective food preservation process for fruits. Drying involves transient heat and mass transfer accompanied by physical, chemical and phase change transformations which may cause changes in product quality as well as the mechanisms of heat and mass transfer (Mujumdar and Devahastin, 2008). In order to improve the quality of the final products and decrease energy consumption, osmotic dehydration pre-treatment prior to drying is used for partial removal of water from food materials by immersion in a hypertonic solution (Deng and Zhao, 2008; Rastogi et al., 2005). The moderate temperature used during osmotic dehydration also helps to retain natural colour and inhibit enzymatic browning (Falade and Igbeka, 2007). In speeding up the water transfer rate in an osmotic dehydration process, a high concentration of sugar solution, high solution temperature, or long treatment time is used. These conditions however result in unfavourable changes in flavour, colour and texture of food (Shi et al., 1995). The ultrasound technology is introduced to assist the time-consuming osmotic or conventional hot-air dehydration processes, and to improve dried product quality.

Ultrasound is a series of sound waves with frequencies above the threshold of human hearing, 18 kHz (Mason, 1998). The ultrasound frequencies between 20 kHz and 10 MHz can be broadly classified into power ultrasound and diagnostic ultrasound. Power ultrasound with frequencies range of 20 kHz to 1 MHz is widely used in food processing due to its physical and chemical effects while diagnostic ultrasound in the range of 1–10 MHz is mainly for medical and industrial imaging purposes (Bhaskaracharya et al., 2009; Kentish and Ashokkumar, 2011; Mason et al., 2005). The low frequency-high intensity power ultrasound has recently increased its interest in food dehydration. It enhances the mass transfer between solid and liquid interfaces with its physical and chemical effects of ultrasonic waves (Mulet et al., 2011). Ultrasonic waves cause cavitation in a liquid medium, a phenomena where of small

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Nomenclature

a, b, n	model constants in Midilli–Kucuk model
B	test blank titration in vitamin C analysis (ml)
C_p	specific heat capacity (J/kg K)
D_{eff}	effective diffusivities (m^2/s)
dT/dt	slope of the temperature versus time curve (K/s)
E	weight of the sample in vitamin C analysis (g)
F	titre in vitamin C analysis (mg/ml)
h	slice thickness (m)
I	effective ultrasound intensity (W/m^3)
k	drying rate constant (min^{-1})
m	mass of sonicated solution (kg)
M	fruit moisture content on a wet basis (w.b.) (g water/g)
M_0, M_e, M_t	initial moisture content, equilibrium moisture content, and moisture content at any time respectively (g water/g dry solids)
MR	moisture ratio (dimensionless)
P_{diss}	ultrasound power dissipated (W)
R^2	coefficient of determination
SG	solid gain (g solid/g)
t	time (s or min)
V	make up volume of liquid extract in vitamin C analysis (ml)
V_s	volume of sonicated solution (m^3)
w	fruit mass (g)
WL	water loss (g water/g)
X	test sample titration (ml)
Y	volume test solution or fitrate in vitamin C analysis (ml)
ΔE	total colour change

Subscripts

i	initial
f	final

bubbles or voids are formed, grow, and collapse due to pressure fluctuation (Mason, 1998). Some cavitation bubbles that collapse asymmetrically when they are close to a solid surface will generate a microjet that hit the solid surface producing an injection of fluid inside the solid and affect the mass transfer phenomena (Cárcel et al., 2007; Mason, 1998; Rastogi, 2011). Whilst bubbles that do not collapse may be stable but continue to increase or decrease in size producing micro-agitation at the interaction of ultrasound in solid–liquid interfaces. The micro-agitation enhances the mass transfer rate by the reduction of solid diffusion boundary layer thickness (Mulet et al., 2011). In a solid medium, the travelling ultrasound produces rapid alternative compressions and expansions resulting a sponge effect in the solid where it helps the liquid to flow out of the solid interchange with the entry of fluid from outside. This effect creates microscopic channels that ease the moisture removal (Cárcel et al., 2012).

The use of ultrasound to improve mass transfer in a fruit dehydration process can be direct or indirect. The solid fruits samples to be dried require an osmotic solution for water transfer. When ultrasound is directly applied in the medium with samples without any barrier such as those of a probe system, the strong cavitation near the tip of the probe may generate free radicals which can be detrimental to foods. However, an ultrasonic probe can deliver about 100 times much higher of ultrasonication intensity than an ultrasonic bath (Santos et al., 2009). For indirect sonication such as using an ultrasonic water bath, ultrasound has to be transferred through water to reach the food placed in a sonicated bath. The ultrasound which is in contact with the food passes through the walls of the sample container and its intensity inside the sample container is lower from the source (Feng and Yang, 2011; Santos et al., 2009).

In recent years, most of the ultrasound assisted pre-treatment studies are widely conducted in ultrasonic bath with fruits like melons, sapota, pineapples, papayas, Malay apple, and strawberries (Fernandes et al., 2008a, 2008b; Fernandes and Rodrigues, 2007, 2008; Garcia-Noguera et al., 2010; Oliveira et al., 2011). Those studies were investigated at an ultrasound bath intensity of 4870 W/m^2 or 100 kW/m^3 with 25 kHz ultrasound frequency. The results showed that ultrasound has a significant effect on water transport during treatments with distilled water and osmotic solutions. Shamaei et al. (2011) who compared low frequency, 35 kHz, and high frequency, 130 kHz, of ultrasound in ultrasound-assisted osmotic dehydration of cranberries showed that low frequency was more favourable in removing water, decreasing hardness (N) and retaining colour. Most of the ultrasound studies have shown significant effects on the moisture diffusion in fruit and vegetables, but they were based on the frequency of ultrasound available commercially. The effect of ultrasound power and amplitude with varying parameters like treatment time and treated medium is scarce.

As the incorporation of non-thermal technology (ultrasound) with the conventional convective drying is suggested to give improvements of both the drying process and products quality, this study was designed to investigate the effect of ultrasound input, immersion time, and osmotic solution concentration on partial and complete dehydration of guava slices using bath and probe ultrasound systems. It included investigations of different pre-osmotic treatments with ultrasound and also measurement of the quality of conventionally hot-air dried guava with ultrasound pre-osmotic treatments.

2. Materials and methods

2.1. *Guava fruit preparation*

Fresh guava fruits (*Psidium guajava*; Kampuchea cultivar Vietnam, GU8) were obtained from Kampung Pelegong, Labu, Negeri Sembilan, Malaysia. Guavas were cut into optimised dimensions of 20 mm × 20 mm × 6 mm, measured to ±0.02 mm using a digital calliper (Mitutoyo, Japan) following previous studies (Kek et al., 2013). The initial moisture content of fresh guava slices and final moisture content of pre-treated guava slices were determined using the oven method at 105 °C for 48 h following the AOAC method, 931.04 (AOAC, 1990). The soluble solids content of the fresh fruit and the concentration of osmotic solution (°Brix) were determined by using a digital hand refractometer (PAL-α, Atago, Japan).

2.2. *Experimental design*

A 4 × 3 × 3 factorial design experiment incorporating four ultrasound input levels, three immersion times and three osmotic solution concentrations for indirect and also direct ultrasound treatments was performed (Table 1). Pre-treatments without ultrasound, 0 kW power and 0% amplitude were the control runs performed in a water bath (BS-21, JEIO