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Effect of hypotonic and hypertonic solutions on impregnation of curcuminoids in coconut slices

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ABSTRACT

The immersion of solid foods into the surrounding hypotonic or hypertonic solution was explored as a method to infuse curcuminoids in coconut slices without altering its matrix. The rate of mass transfer of moisture, solid and curcuminoid with or without application of ultrasound was studied for the surrounding solutions of sucrose (12.5%) and/or sodium chloride (2.5 and 5.0%) consisting of curcuminoids. The highest diffusion coefficient of curcuminoids (1.78×10^{-10} m^2/s) was found to be in a situation, when curcuminoids were dissolved in 2.5% sodium chloride solution, which was further enhanced by the application of ultrasound to 1.81×10^{-10} m^2/s. The direction of moisture and solute mass transfer was dependent on the osmotic pressure of the surrounding solution as well as the osmotic pressure in the coconut slices. The extent and rate of mass transfer can be varied by varying the type and concentration of solutes in the surrounding solution.

Industrial relevance: The knowledge provided by this work may be useful for impregnation of bioactive compounds in solid foods without altering their natural matrix. The extent and rate of infusion of bioactive compounds can be changed by varying the type of surrounding solution from hypotonic to hypertonic solution. Further, the application of external field such as ultrasound can result in enhanced mass transfer of bioactive compounds. This technique may be helpful in producing foods with enriched bioactive compounds, besides providing diversified products in terms of taste and nutrition.

1. Introduction

The development of foods that promote health and well being is one of the key research priorities of food industry (Klaenhammer & Kullen, 1999). This trend has favored consumption of foods enriched with physiologically active components such as pre and probiotics, vitamins, minerals, dietary fiber, fish oils and plant sterols (Betoret et al., 2003). American Nutraceutical Association has defined nutraceutical as a substance that is food or isolated or purified from foods, which provides medical or health benefits, including the prevention and treatment of disease. Such products may range from isolated nutrients, dietary supplements and specific diets to genetically engineered designer foods, herbal products, and processed foods such as cereals, soups and beverages. Antioxidants, natural colorants (e.g. lycopene, carotenoids), minerals, probiotic bacteria or vitamins are several examples of nutraceutical and they provide added advantages.

Homogeneous distribution of physiologically active compounds in foods can be obtained by mixing in formulating products when the product is in the form of powder, liquid state or restructured foods. However, it becomes much more difficult for production of functional food from solid foods, which maintain their natural matrix or cellular structure (Fito, 1994). Impregnation of physiologically active compounds such as minerals (Barrera, Betoret, & Fito, 2004; Gras, Vidal-Brotons, Betoret, Chiralt, & Fito, 2002), phenolic compounds (Rozek, Achaerandio, Guell, Lopez, & Ferrando, 2009, 2010; Rozek, Garcia-Perez, Lopez, Guell, & Ferrando, 2010), curcuminoids (Bellary, Sowbhagya, & Rastogi, 2011), probiotics (Alzamora et al., 2005), and vitamins (Hironaka et al., 2011) into solid food tissue by employing osmotic treatment was demonstrated by many researchers. Osmotic treatment had many fold advantages which include food formulation by reducing the water activity and supplementing the foods with compounds that modify its functional, structural and nutritional properties (Alzamora et al., 2005; Fito et al., 2001). During osmotic dehydration, several flows take place such as water removal from food material to hypertonic solution and, simultaneously, in counter current solute uptake. Additionally, soluble compounds of the foodstuff can accompany the water flow. Several mechanisms such as osmosis, diffusion and hydrodynamic mechanisms take part in the mass transfer phenomena. (Rastogi, Angersbach, & Knorr, 2000; Rastogi, Raghavarao, Niranjan, & Knorr, 2002).

A number of techniques proposed to enhance the inherently low rate of osmotic mass transfer include high pressure (Rastogi & Niranjan, 1998), pulsed electrical field (Rastogi, Eshtiaghi, & Knorr, 1999), partial vacuum (Rastogi & Raghavarao, 1996) or centrifugal force (Azuara, Garcia, & Beristain, 1996). The use of ultrasound in combination with osmotic dehydration results in higher rate of water loss and solute gain at a lower solution temperature, while preserving the natural flavor, color

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and heat-sensitive nutritive components. The application of ultrasound results in acoustical cavitations leading to the production of minute vapor-filled bubbles that collapse rapidly, resulting in complete and accelerated degassing of immersed solid. Ultrasound wave traveling through a solid medium can also generate a series of alternative compressions and expansions, in a similar way to a sponge when it is squeezed and released repeatedly (sponge effect) (Stojanovic & Silva, 2007). The higher surface tension force caused by this mechanism maintains the moisture inside the capillaries of the material creating microscopic channels (increased cell permeability or lower resistance), which may make the moisture removal easier (Carcel, Benedito, Rossello, & Mulet, 2007; Deng & Zhao, 2008). Also, the oscillatory motion of a sound wave causes acoustic streaming (leading to the enhancement of mass transfer) (Fernandes, Gallao, & Rodrigues, 2008; Rastogi, 2011).

Turmeric (*Curcuma longa* L.) is a rich source of phenolic compounds namely curcuminoids with the principle ingredient being curcumin and other two analogs such as demethoxycurcumin and bisdemethoxycurcumin (Govindarajan, 1980). Curcumin was demonstrated to possess anti-inflammatory, antimicrobial, antioxidant, antiparastic, antimutagenic and anticancer activity (Goel, Kunnumakkara, & Aggarwal, 2008; Joe, Vijaykumar, & Lokesh, 2004). Hsu and Cheng (2007) have demonstrated that curcumin with doses up to 3600–8000 mg daily for 4 months did not result in discernible toxicities except mild nausea and diarrhea. Jiao et al. (2009) pointed out that curcumin has the potential to affect systemic iron metabolism, particularly in a setting of subclinical iron deficiency.

The rate and extent of infusion of physiologically active compounds in to the solid foods were found to be dependent on the type and concentration of surrounding solution (hypotonic or hypertonic). Bellary et al. (2011) indicated that the increase in concentration of sucrose solutions resulted in a decrease in the incorporation of curcuminoids and the highest incorporation of curcuminoids could be achieved when the surrounding solution was distilled water.

The objective of the present work were to study the impregnation of curcuminoids into coconut slices in binary and ternary osmotic (or surrounding) solutions consisting of sucrose or/and sodium chloride with or without ultrasound and to evaluate the possible mechanism of mass transfer during impregnation.

2. Materials and method

2.1. Preparation of sample

Fully mature coconut with brown skin and thick meat (about 12 months from flowering) were procured from a local market. The shell of the coconut was manually removed. From the coconut kernel, thus obtained, coconut slices of length 20 mm and thickness 2 mm were cut.

2.2. Osmotic treatment

The binary osmotic solutions of sodium chloride (2.5 and 5%, w/w), sucrose (12.5%, w/w) and their combinations (ternary solutions consisting of 2.5 or 5% sodium chloride sucrose + 12.5% sucrose, w/w) were prepared by dissolving the required amount of solute in water. The solutions were made and kept overnight at room temperature (20 °C) before use to ensure complete dissolution of sodium chloride and sucrose. The coconut slices taken from the same coconut were blotted with tissue paper to remove external moisture. These pieces were pre-weighed and subjected to osmotic treatment in respective vessels containing osmotic solutions (0.13 g/100 ml water soluble curcumin) with or without intermittent ultrasound treatment in a sonication bath (Model UCB 40, 35 kHz, amplitude 100%, 1 min on and 15 min off). Immediately after the ultrasound treatment, the vessels were kept on a platform (which has a gyratory motion) on a stirred water bath at ambient temperature. The standard curcumin powder was made water soluble by preparing 3% solution in 1:1 ratio of propylene glycol and Tween 60 (Sowbhagya, Smitha, Sampathu, Krishnamurthy, & Bhattacharya, 2005) Ratio of the volume of the sample (solid) to that of osmotic solution (liquid) was maintained at 1:5. The samples were withdrawn at the end of 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 h of immersion time, rinsed quickly in a stream of water to remove osmotic solution and blotted with tissue paper and then weighed. The samples were then dried in a vacuum oven at 60 °C for about 24 h. The moisture and solid contents were expressed in terms of kg of water/kg of initial dry solids and kg of solid/kg of initial dry solids, respectively. All the experiments were done in triplicate and the average value was taken.

Coconut slices were also subjected to varied concentration of sucrose solution (0, 5, 10, 12.5, 13.5,15,20 and 25°Bx). After 5 h of osmotic treatment the samples were drawn from solution and moisture loss and solid uptake was calculated to know the osmotic pressure and total soluble solids of coconut.

2.3. Estimation of curcuminoid content

The curcuminoid content in coconut was estimated as per ASTA (1985) procedure. One gram of osmotic treated and finally dried coconut samples was ground using a pestle and mortar. The ground sample was mixed with 5 ml of acetone from Merck (Mumbai, India) to facilitate color extraction. The extract was decanted and filtered through a cotton plug. This step of extraction was repeated until all the color was extracted. The extracts were pooled and the volume was made up to 50 ml with acetone and centrifuged (4000 rpm for 15 min). The absorbance of the supernatant was measured at 425 nm using acetone as blank solution. The curcuminoid content was calculated using the following equation.

$$\text{Curcuminoid content}\ (mg/100g) = \frac{D_x}{D_s}\frac{W_s}{W_x}\frac{A_x}{A_s} \times 10^5 \tag{1}$$

W_s, D_s and A_s are the weight, dilution and the absorbance of the standard curcuminoids and were reported to be 0.0025 g, 1000 ml and 0.42, respectively. W_x, D_x and A_x are the weight, dilution and the absorbance, respectively pertaining to the sample.

2.4. Determination of osmotic pressure of surrounding solution

The osmotic pressure (π) of the concentrated solution is related to water activity of the solution as given by the following equation (Rastogi & Raghavarao, 1994; Toledo, 1991):

$$\pi = -2.3026\left(\frac{RT}{V}\right) log\ \ a_w \tag{2}$$

where R is the gas constant (8.314 J/(K mol)), T is the temperature in K, V is the molar volume (18 ml/mol of water) and a_w is the water activity.

The water activity can be expressed in terms of mole fraction of water by the following equation (Norrish, 1966; Toledo, 1991):

$$log\ \ a_w = log\ \ x_w - k(1-x_w)^2 \tag{3}$$

where x_w is the mole fraction of water and k is a constant, which depends upon the type of osmotic agent. In a multi component system involving two solutes, the water activity can be expressed as (Norrish, 1966):

$$a_w = (a_{w1})_0 (a_{w2})_0 \tag{4}$$

where $(a_{w1})_0$ and $(a_{w2})_0$ are the water activity (from Eq. (3)) of each component in the solution.